Workshop on the Role of Time and Space Considerations in USAE Ecosystem Modeling and Restoration

Abstract

The Engineer Research and Development Center (ERDC) is involved in research on a variety of hydraulic, hydrodynamic, hydrologic, water quality, and biological modules, algorithms, and models to address management issues within the Corps of Engineer Districts and Divisions. Within the Environmental Laboratory, there is a major emphasis on linking or integrating physical, chemical, and biological models to address ecosystem restoration and management problems. These models span a broad range of temporal and spatial scales. One of the current issues in ecosystem modeling is how one links modules and models across the range of time and length scales so that appropriate tools can be used to help reach decisions on ecosystem restoration, conservation, and management projects.

This workshop will focus on an integrated process of selecting, applying, and interpreting modeling tools appropriate for the range of environmental issues and decisions being addressed by Corps of Engineer Districts and Divisions. The workshop will initiate the process by beginning with the end in mind – what decisions need to be made, what management actions are proposed, and for which systems (e.g., How can submerged aquatic vegetation be re-established as part of the restoration of the Upper Mississippi River? How could barrier island formation and re-establishment of Gulf of Mexico coastal wetlands reduce future hurricane damage to coastal MS and LA? What stream channel and riparian wetland designs would be most appropriate for restoring urban streams in Philadelphia? Which reservoir rule curves or operating regimes will minimize conflicts among project purposes and contribute to more natural downstream conditions?)

Four modules will be discussed as part of an integrated process for using models to support decisions on environmental issues: Bounding the Problem; Selecting Appropriate Tools for the Problem; Solving the Problem, and Resolving the Issue.

Bounding the Problem begins by developing a conceptual model of the problem, the management endpoints, the relevant ecological indicators whose response relates directly to decisions to be made about that endpoint, and the dominant processes expected to affect the system response. A number of order of magnitude estimators (OME) and empirical models (relationships) exist that can be used not only to help bound the problem, but also refine the conceptual model, and, if needed, help select appropriate dynamic models for evaluating engineering design or management scenarios. One of the earliest OME for river systems was the Reynolds number, which identified characteristic time and space scales for laminar flow. Densimetic Froude numbers have been used to estimate thermal stratification potential in reservoirs. Nutrient loading models or empirical relationships among annual TP loads, mean depth, and seasonal average chlorophyll have been used to evaluate management practices for reducing reservoir

eutrophication. In addition, these empirical relationships begin to define the relevant time and space scales of interest.

The OME and empirical relationships can help us Select Appropriate Tools for the Problem. Note that tools is plural, not singular. The corollary to Box (All models are wrong, but many models are useful) is that there is no perfect tool, but there are a number of imperfect tools that provide weight of evidence in evaluating solutions to environmental management problems. Understanding time and space relationships helps select models that simulate the desired ecosystem responses (e.g., cyanobacteria biomass) through appropriate process formulations. Some early Great Lakes phytoplankton models considered the dynamics of luxury uptake of nutrients across the algal cell wall (seconds) to modify daily growth rates for algal assemblages within the average summer photic zone. While the mismatch of time and space scales for model algorithms is apparent in this example, more subtle differences can exist and should be considered in model selection and application. Rules of thumb for considering compatible time and space scales for linking model subroutines or modules will be provided.

Solving the Problem means that both a solution, and its certainty (uncertainty), are provided to the decision-maker or manager. In many instances, the estimate of certainty is as important as the solution. In fact, a margin of safety (MOS) is required as part of all Total Maximum Daily Load (TMDL) studies. A number of approaches have been developed for incorporating uncertainty in model output for both empirical and dynamic models (e.g., First Order Error Analysis, Modified Chebyshev Inequality, Latin Hypercube, Regional Sensitivity Analysis, Generalized Likelihood Uncertainty Estimator). Uncertainty considerations will be discussed as part of this session.

Rarely are decisions made solely on environmental considerations. Scientifically sound environmental solutions are necessary, but not necessarily sufficient for resolving environmental issues. Resolving the Issue includes the scientific solution in conjunction with economic, social welfare, policy, and political considerations. While this is outside the realm of many engineering solutions, awareness of the linkages with these other factors can increase the likelihood that the environmental solution will be incorporated in the decision. Several approaches for integrating environmental, social, and economic results will be discussed in this session.

Development of scientifically defensible and useful decision support systems can build on an integrated process of selecting, applying, and interpreting modeling tools appropriate for the range of environmental issues and decisions being addressed by Corps of Engineer Districts and Divisions The morning session will set the stage for open forum discussion in the afternoon session.

Role of Time and Space Considerations in USAE Ecosystem Modeling and Restoration Workshop Summary

Introduction

The nation's water resources are affected by human activities at multiple scales from urban communities to major river basins. Because of the impacts of these activities, the Corps of Engineers has ecosystem management and restoration projects that also span multiple scales, from urban streams to the Upper Mississippi River. However, technologies for system-wide assessment for sustainable and adaptive management at these multiple scales are not readily available.

The System-Wide Water Resources Program (SWWRP) is developing decision support systems to assist Corps of Engineer Districts and Divisions in management and ecosystem restoration decisions that need to be made at multiple scales. A workshop was held at the Engineering Research and Development Center, Vicksburg, MS on June 6, 2007 to discuss: 1) the process for solving ecosystem restoration, protection, and management problems, 2) the role of time and space in this problem-solving process, 3) desired attributes of a decision support system to assist in managing and restoring aquatic ecosystems, and 4) the process of resolving engineering and environmental issues.

The agenda for the workshop is shown in Attachment 1 and the workshop participants are listed in Attachment 2.

SWWRP

The SWWRP goal is to provide the Corps and its partners with the capabilities to: 1) balance resource development with ecosystem requirements; 2) restore and manage water resources over multiple spatial and temporal scales; and 3) achieve environmental sustainability.

To achieve this goal, SWWRP will focus on developing decision support systems that assemble and integrate the essential components of water resources management to: 1) transition from site-specific to holistic, integrated assessment and management; 2) apply current and improved approaches for forecasting system-wide outcomes of management; and 3) expedite alternative evaluation, trade-off analysis, and decision support across watersheds and basins.

Literature Review: Time, Space, and The Decision-Making Process

In the morning session, Dr. K. Thornton, FTN, presented the results of an ERDC study that considered the role of time and space in the decision-making process and the implications of time and space for decision support systems related to engineering and environmental issues.

This session focused on an integrated process of selecting, applying, and interpreting modeling tools appropriate for the range of environmental issues and decisions being addressed by Corps of Engineer Districts and Divisions. This integrated process is initiated by beginning with the end in mind – what decisions need to be made, what management actions are proposed, and for which systems (e.g., How can submerged aquatic vegetation be re-established as part of the restoration of the Upper Mississippi River? How could barrier island formation and re-establishment of Gulf of Mexico coastal wetlands reduce future hurricane damage to coastal MS and LA? What stream channel and riparian wetland designs would be most appropriate for restoring urban streams in Philadelphia? Which reservoir rule curves or operating regimes will minimize conflicts among project purposes and contribute to more natural downstream conditions?)

Four modules were discussed as part of this integrated process for using models to support decisions on environmental issues: Bounding the Problem; Selecting Appropriate Tools for the Problem; Solving the Problem, and Resolving the Issue.

Bounding the Problem begins by developing a conceptual model of the problem identifying the management endpoints, linking the endpoint to the relevant ecological indicators whose response relates directly to decisions to be made about that endpoint, and postulating dominant processes expected to affect the system response. A number of order of magnitude estimators (OME) and empirical models (statistical relationships) exist that can be used not only to help bound the problem, but also refine the conceptual model, and, if needed, help select appropriate dynamic models for evaluating engineering design or management scenarios. One of the earliest OME for river systems was the Reynolds number, which identified characteristic space (length) scales for laminar flow. Densimetic Froude numbers have been used to estimate thermal stratification potential in reservoirs. Nutrient loading models or empirical relationships among annual TP loads, mean depth, and seasonal average chlorophyll have been used to evaluate management practices for reducing reservoir eutrophication. These OME and empirical relationships can help define the relevant time and space scales of interest.

The OME and empirical relationships also can help in Selecting Appropriate Tools for the Problem. Note that tools is plural, not singular. A corollary to Box's theorem, (All models are wrong, but many models are useful) is that there is no perfect tool, but there are a number of imperfect tools that provide weight of evidence in evaluating solutions to environmental management problems. Understanding time and space relationships helps select models that simulate the desired ecosystem responses (e.g., cyanobacteria biomass) through appropriate process formulations. Some early Great Lakes phytoplankton models considered the dynamics of luxury uptake of nutrients across the algal cell wall (time scale of seconds) to modify daily growth rates for algal assemblages within the average summer photic zone. While the mismatch of time and space scales for model algorithms is apparent in this example, more subtle differences can exist and should be considered in model selection and application. Rules of thumb for considering compatible time and space scales for linking model subroutines or modules included having three qualitatively different hierarchical levels with different process speeds, being able to adequately describe system dynamics with 3-5 sets of variables, and using "rules of 10" to evaluate and determine spatial hierarchical levels.

Solving the Problem means that both a solution, and its certainty (uncertainty), are provided to the decision-maker or manager. In many instances, the estimate of certainty is as important as the solution. In fact, a margin of safety (MOS) is required as part of all Total Maximum Daily Load (TMDL) studies. A number of approaches have been developed for incorporating uncertainty in model output for both empirical and dynamic models (e.g., First

Order Error Analysis, Modified Chebyshev Inequality, Latin Hypercube, Regional Sensitivity Analysis, Generalized Likelihood Uncertainty Estimator). Uncertainty considerations, particularly those that estimate risk, need to be part of any DSS.

Rarely are decisions based solely on environmental considerations. Scientifically sound environmental solutions are necessary, but not always sufficient for resolving environmental issues. Resolving the Issue includes a scientific solution in conjunction with economic, social welfare, policy, and political considerations. While this is outside the realm of many engineering solutions, awareness of the linkages with these other factors can increase the likelihood that the environmental solution will be incorporated in the decision. Several approaches for integrating environmental, social, and economic results have been developed including Frontier analysis and structured equation models.

Development of scientifically defensible and useful decision support systems can build on an integrated process of selecting, applying, and interpreting modeling tools appropriate for the range of environmental issues and decisions being addressed by Corps of Engineer Districts and Divisions The morning session set the stage for an open forum discussion in the afternoon session.

Discussion

P. Deliman, ERDC, opened the afternoon session by summarizing the challenges identified for ecosystem modeling and restoration. Some of these challenges included: overcoming time and space incompatibilities among high and low fidelity models; incorporating feedback between coupled models; developing optimization approaches for incorporating trade-off analyses; and assessing model performance by incorporating uncertainty. This led to an open discussion on decision-support systems and needs of both the research and management communities. The Upper Mississippi River and its approaches to ecosystem restoration and decision support systems were used as the example to initiate discussion.

There are over 40 objectives that guide the development of design criteria for restoring the upper Mississippi River (UMR) system. While this number of objectives might seem daunting, in general, the number of objectives decreases as the scale of the project decreases. For example, although there are 41 objectives for the entire UMR, there are 4-5 objectives that pertain to an individual navigation pool project.

Hydrologic and hydraulic, sediment transport, and water quality information is available for most of the river system. Landscape perspectives have been used to target areas for restoration activities such as island and wetland creation, backwater reconnections, etc. While physicochemical information is available for most of the system, biological information, in general, is lacking. Habitat evaluation procedures (HEP) are available for analysis of some restoration alternatives, but additional tools are needed, including ecological models, which represent a missing element in the restoration process.

Workshop participants indicated needed ecological models include bio-energetic, population dynamic, and ecological response models. Ecosystem models that can be used to predict incremental or unit changes in various ecosystem services per km or surface ha might permit socioeconomic valuation methods to be used for benefits estimation. In addition, having natural history information on not just individual species, but also communities and ecosystems would be valuable.

One of the areas of emphasis for the UMR is establishing the historical functions and processes of the Mississippi River, its backwater areas, and floodplain. The historical Mississippi River processes and their interactions can provide a frame of reference for comparing restoration alternatives. For nearly all restoration projects, establishing an appropriate frame of reference is a critical need.

Coastal restoration in the Louisiana (LA) area was contrasted with the UMR. In general, the LA coastal restoration effort has similar needs to the UMR. A system-wide perspective is needed for LA. A basin by basin approach has been used previously. Following Hurricanes Katrina and Rita, the need for this system-wide perspective has become even more apparent. In addition, an approach or approaches for developing optimal project sequencing would be very useful. In many cases, synergistic interactions among projects can be attained if projects can be sequenced in a certain order.

A research need for both the UMR and LA coastal restoration is the capability to estimate and quantify environmental benefits. Environmental benefits need to be quantified not only economically, but also socially. Realistic and quantifiable performance measures are needed to document these environmental benefits for multiple alternatives. In addition, the risk and uncertainty associated with different tools and their associated results must be quantified. As these tools are developed, decision-support systems need to have the capability of incorporating multi-criteria decision analytic approaches to integrate results from different tools and different uncertainty or risk estimates with estimates of environmental benefits and their uncertainty or risk estimates.

There were apparent differences of opinion among workshop participants on what should be external or internal within a decision-support system. Nearly everyone agreed the goals and objectives are external to the decision-support system and are considered essential inputs. However, there did not appear to be consensus on whether models – conceptual to dynamic – are external or internal to the decision-support system. Several workshop participants thought that having a description of the various tools in a DSS would be useful in deciding which models, tools, approaches to consider in ecosystem protection, restoration, and management.

One of the next steps proposed was to conduct a workshop to discuss information flow and modeling through decision-support systems. This workshop could also discuss the minimum or essential elements of a decision support system, and the desired elements. The UMR, again, might provide a useful prototype for illustrating how information flow and modeling might proceed at multiple scales because the UMR areas of emphasis in the near term include Pools 5 and 18, the Illinois River, and the middle Mississippi River.

For example, a DSS framework for the UMR has been proposed (Figure 1) and is in the process of being developed.

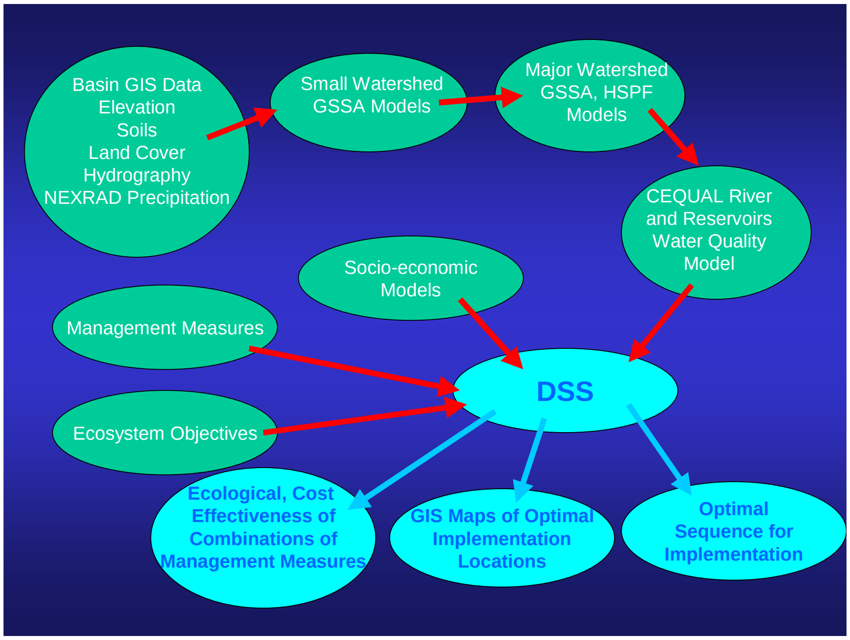

Figure 1. Upper Mississippi River DSS framework.

In an earlier SWWRP workshop, a slightly different DSS framework was proposed (Figure 2). These could be used as templates for discussion at the next workshop.

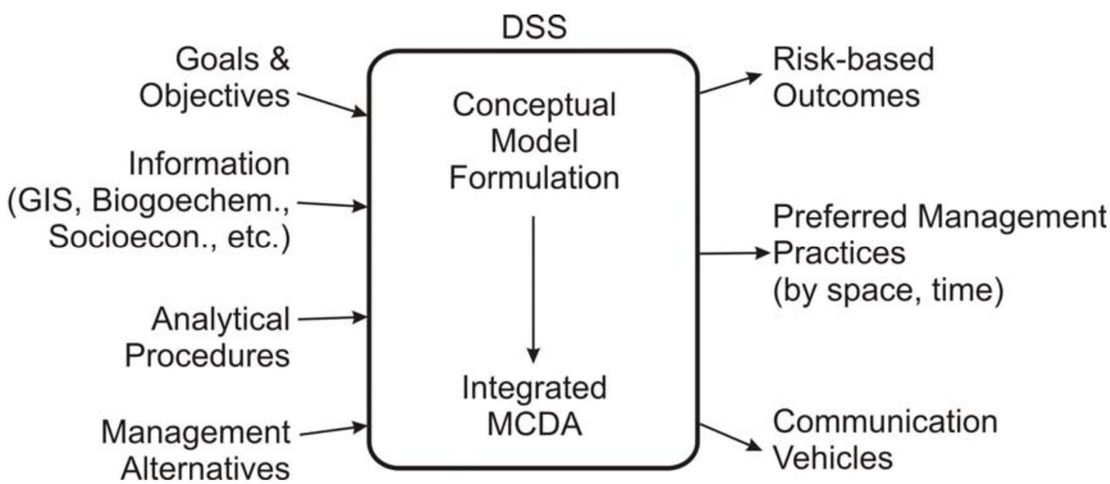

Figure 2. Possible DSS framework for SWWRP.

Workshop on the Role of Time and Space Considerations in USAE Ecosystem Modeling and Restoration

ERDC EL Class Room

Vicksburg, MS
6 June 2007 Tentative Workshop Agenda

Time	Topic	Individual
0830	Welcome, Introductions, Workshop Purposes: 1. Discuss a Process for Integrating Ecosystem Modeling and Restoration in Decision-Making. 2. Discuss the Role of Time and Space in the Integrated Decision Making Process. 3. Provide a Forum for Discussion of Ecosystem Modeling, Restoration, and Decision-Making Issues.	S. Ashby, ERDC
0847	Challenges in Ecosystem Modeling and Decision-Making: USAE District and Division Needs Workshop: • Summary. • Questions and Discussion.	K. Thornton, FTN
0907	An Integrated Process for Ecosystem Modeling, Restoration and Decision-Making: • Use a suite of models. • Start with simple methods; complicate only if needed. • Keep it simple. • Questions and Discussion.	K. Thornton
0927	Bounding the Problem: • Order of Magnitude Estimates. • Empirical Relationships. • Introduction to Time and Space Considerations. • Questions and Discussion.	K. Thornton
0957	**BREAK**	

Time	Topic	Individual
1015	Selecting Tools for the Problem: • Time and Space – Hierarchy Theory. • General Guidance and Rules of Thumb. • Questions and Discussion.	K. Thornton
1050	Solving the Problem: • Chaos, Complexity Theory. • Incorporating Uncertainty. • Corroboration and Collaborative Approaches. • Questions and Discussion.	K. Thornton
1120	Resolving the Issue: • Panarchy Theory. • Integrating Socioeconomic Information. • Moving Toward Decisions. • Questions and Discussion.	K. Thornton
1150	Afternoon Session	K. Thornton
1200	**LUNCH**	
1300	Third Workshop Summary	P. Deliman
1320	Open Forum for Discussion: • Process for Integrating Ecosystem. Modeling and Restoration in Decision-Making. • From Montana & Minnesota to Louisiana. • Environmental Benefits Analyses. • Other Topics.	All
1500	**BREAK**	
1515	Open Forum (Continued)	
1600	Action Items, Next Steps	K. Thornton
1615	Concluding Remarks	S. Ashby
1630	**ADJOURN**	

Workshop Participants

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Ecological Modeling: Principles to Build and Integrate Capability

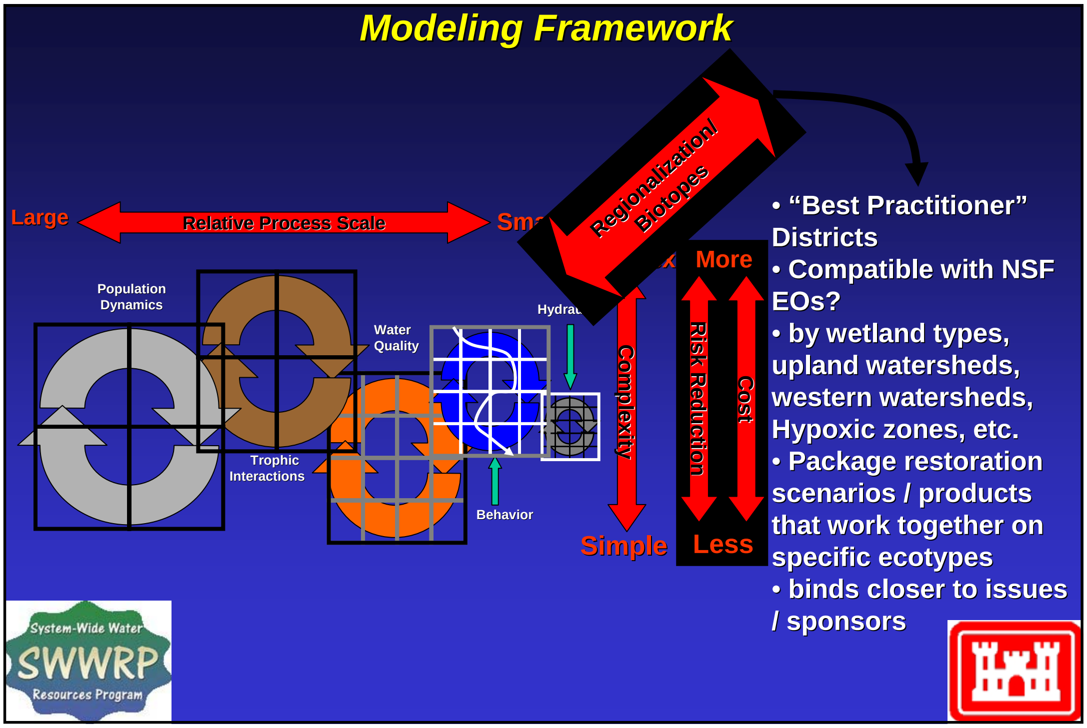
Workshop Summary

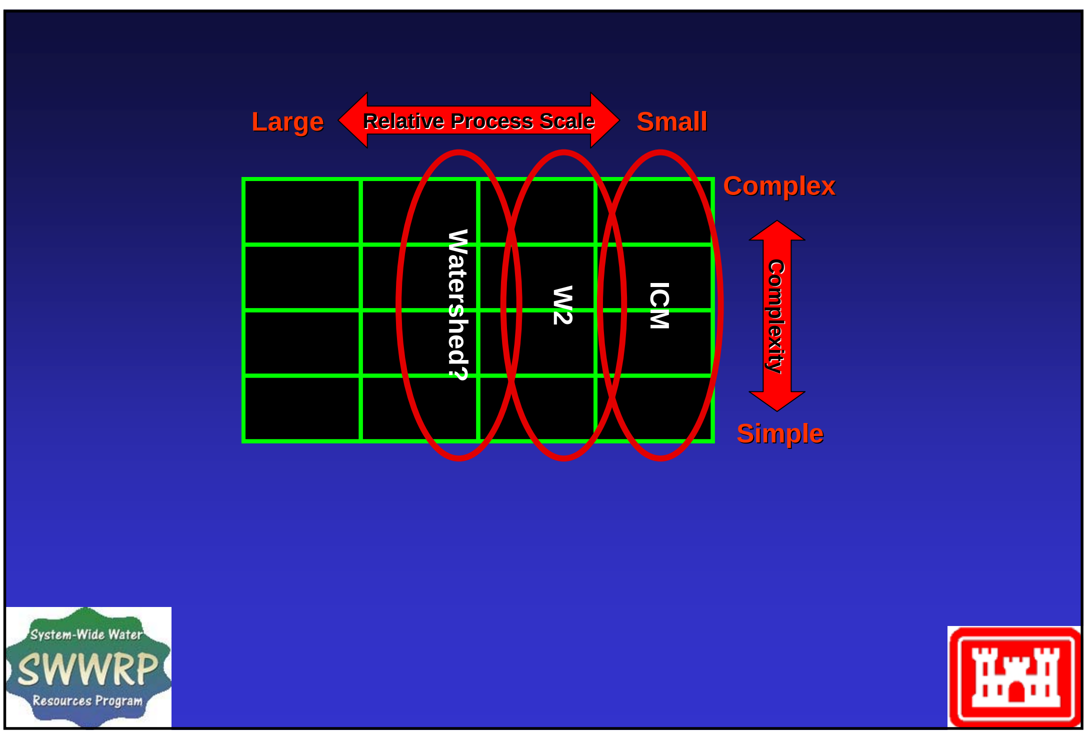
06JUN07

The Vision:

Engineers & Ecologists Working Together with Harmony and Mutual Respect

Can the Vision Be Achieved?


Modeling Framework
Large
Relative Process Scale
Sm
Regionalization/
Biotopes
More
Less
Population
Dynamics
Water
Quality
Hydrau
Trophic
Interactions
Behavior
Complexity
Simple
Risk Reduction
Cost
• "Best Practitioner" Districts
• Compatible with NSF EOs?
• by wetland types, upland watersheds, western watersheds, Hypoxic zones, etc.
• Package restoration scenarios / products that work together on specific ecotypes
• binds closer to issues / sponsors
System-Wide Water
SWWRP
Resources Program


Large
Relative Process Scale
Small
Complex
Complexity
Simple
Watershed?
W2
ICM
System-Wide Water
SWWRP
Resources Program

Workshop Goals Day 1:

- Clearly articulate 2-4 integrating, binding concepts upon which we can ordinate ERDC eco-modeling capability
  - Integrated Reference Frameworks Concept (scale)
  - Ecological Modeling Similitude Analysis (simple to complex)
  - B/C analysis of simple to complex to assess risk reduction benefit of complex tools – coincident applications
  - Address issues in contrast to building tools
  - Build capacity – build models and modelers
  - dam removal is emerging mission area
  - From CHL – what do ecologists need?

System-Wide Water SWWRP Resources Program

Eco-modeling Challenges

- *Overcome time and space scale incompatibilities*
- *Incorporate feedbacks among coupled models*
- *Select an optimum environmental model for each application*
- *Expand use of environmental engineering models*
- *Special applications and systems*
- *Assess model performance*

System-Wide Water SWWRP Resources Program

Workshop on the Role of Time and Space Considerations in USAE Ecosystem Modeling and Restoration
ERDC EL Class Room
Vicksburg, MS
6 June 2007

Agenda

Time	Topic	Individual
0830	Welcome, Introductions, Workshop Purposes: 1. Discuss a Process for Integrating Ecosystem Modeling and Restoration in Decision-Making 2. Discuss the Role of Time and Space in the Integrated Decision Making Process 3. Provide a Forum for Discussion of Ecosystem Modeling, Restoration, and Decision-Making Issues.	S. Ashby, ERDC
0845	Challenges in Ecosystem Modeling and Decision-Making: USAE District and Division Needs Workshop • Summary • Questions and Discussion	K. Thornton, FTN
0905	An Integrated Process for Ecosystem Modeling, Restoration and Decision-Making • Use a suite of models. • Start with simple methods; complicate only if needed. • Keep it simple • Questions and Discussion	K. Thornton
0930	Bounding the Problem • Order of Magnitude Estimates • Empirical Relationships • Introduction to Time and Space Considerations • Questions and Discussion	K. Thornton
1000	**BREAK**	

Time	Topic	Individual
1015	Selecting Tools for the Problem • Time and Space – Hierarchy Theory • General Guidance and Rules of Thumb • Questions and Discussion	K. Thornton
1050	Solving the Problem • Chaos, Complexity Theory • Incorporating Uncertainty • Corroboration and Collaborative Approaches • Questions and Discussion	K. Thornton
1120	Resolving the Issue • Panarchy Theory • Integrating Socioeconomic Information • Moving Toward Decisions • Questions and Discussion	K. Thornton
1150	Afternoon Session	K. Thornton
1200	**LUNCH**	
1300	Ecosystem Modeling Workshop: Looking for a Common Theme • Summary • Questions and Discussion	P. Deliman
1320	Open Forum for Discussion • Process for Integrating Ecosystem Modeling and Restoration in Decision-Making • From Montana & Minnesota to Louisiana • Environmental Benefits Analyses • Other Topics	All
1500	**BREAK**	
1515	Open Forum (Continued)	
1600	Action Items, Next Steps	K. Thornton
1615	Concluding Remarks	S. Ashby
1630	**ADJOURN**	

Workshop on Ecosystem Modeling and Restoration:
Time, Space, and Integrated DSS

Kent Thornton
FTN Associates

Workshop Agenda

- Workshop Summary
- Integrated Process
- Bounding the Problem
- Selecting Tools
- Solving the Problem
- Resolving the Issue
- Open Discussion Forum (Afternoon)

SWWRP Workshop June 2006

- Challenges in Ecosystem Modeling and Decision-Making:

  District and Division Needs
- Listening Workshop
  - Managing and Restoring Aquatic Ecosystems
  - Decision Support Systems Tools

District and Division Needs

- Upper MS River Restoration
- Minnesota River Restoration
- Everglades Restoration
- Puget Sound Improvement
- Navigation Pool Enhancement
- Wetland Creation, Restoration
- Beach Nourishment
- Shoreline Protection

District and Division Needs

- GOM Coastal Restoration
- Chesapeake Bay Restoration
- Urban Stream Restoration
- Selective Withdrawal Design
- Island Creation
- Fish Passage Structures

Desired Outcomes

- Ecosystem Services Restored
- Floodplain Restoration
- Wet Prairie Restoration
- Endangered Species Habitat
- Invasive Species Eradication/Mgt
- “Natural” Down-stream Flow Regime

Desired Outcomes

- Stormwater Management
- Beach Nourishment
- Mine land Reclamation
- Urban stream ecosystems

Temporal – Spatial Interests

- Time
  - Hour
  - Day
  - Season
  - Annual
  - Decadal
  - Century
- Space
  - Meter
  - Hectare
  - Watershed
  - Estuary
  - Basin

Tools

- HEC-RAS
- HEC 6
- FLO2D
- CE-QUAL-W2
- ICM
- IBI
- HIS
- HGM . . .
- HEAT
- GSSA
- HSPF
- CE-QUAL-RIV
- SIAM
- HEP/mHEP
- SAM
- URGWOM . . .

Tool (Modeling) Wish List

- User Friendly Desktop Interface
- Scalable Eco Models (Reach to Basin)
- Realistic Field Data Requirement
- Interactive Benefit Impact Display
- Easily Communicated Output
- Linkable/Inter-active Models
- Auto-tracking Changes and Updates
- GIS Interactive Models
- Quan/Qual Habitat Valuation
- On-the-fly Design Alt.

Additional Everglades Tools

- Enhanced Hydrol. Models
- Vegetation Succession Models
- Biotic species - Community Model
- Restoration Optimization
- Landscape WQ Models
- Soil/Sediment Transport/Process Models
- Landscape Evolution Model
- ET Tool

Decision-Making

- Multi-Criteria Decision Analysis
  - Ultimate Objective – Inject Science into the Decision-Making Process
  - MCDA Structured Process for Decision-Making
    - Trade-off Analyses
    - Benefit – Cost – Risk
    - Certainties – Uncertainties

Upper MS River DSS Framework

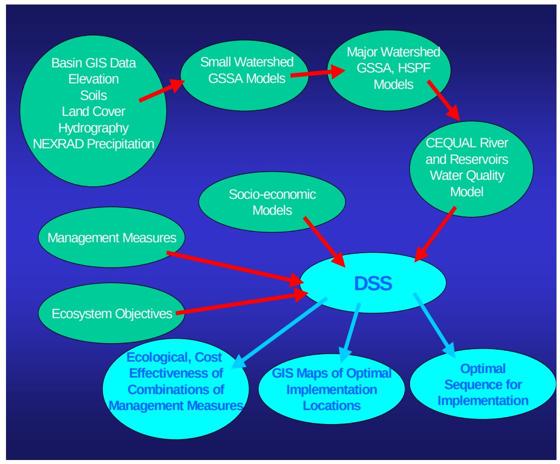


Figure 1. Upper Mississippi River DSS framework.

General DSS Framework

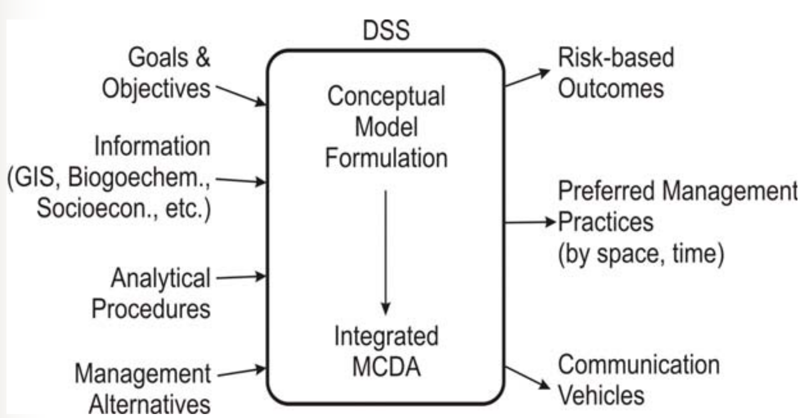


Figure 2. Possible DSS framework for SWWRP.

Questions?

Discussion

Integrated Process

Ecosystem Modeling, Restoration, and Decision-Making

Bottom Line

- **It's the Whole;**
  Not the Parts
- **It's the Process;**
  Not the Product
- **It's the Issue;**
  Not the Problem

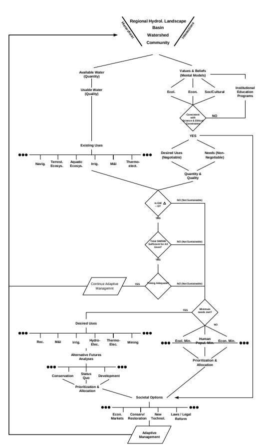
SWWRP Goals

- **Provide the Corps and its Partners with the Capabilities to:**
  - **Balance Resource Development with Ecosystem Requirements**
  - **Restore & Manage Water Resources Over Multiple Time/Space Scales**
  - **Achieve Environmental Sustainability**

SWWRP Goals

- SWWRP Will Achieve Goals By Developing DSS to:
  - Transition From Site-Specific to Holistic, Integrated Assessment and Management
  - Apply Current/Improved Methods for Forecasting System-wide Mgt Outcomes
  - Permit Alternative Evaluation, Trade-off Analysis and Decision Support Across Watershed and Basins

Solving Engineering Problems



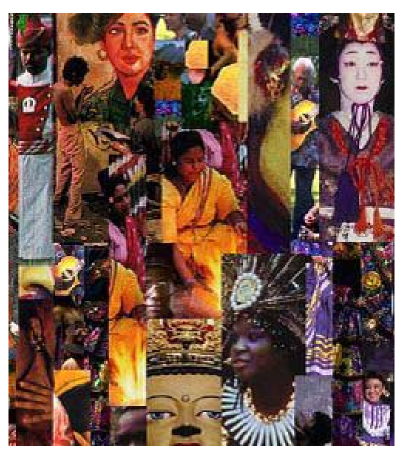
- Problem Identification
- Scoping
- Design
- Build
- Operate
- Next Problem

Engineering Problem => Environmental Management

- Problem or Issue?
  - Problems have *Solutions*
    - Engineers
    - Natural Scientists
  - Issues have *Resolutions*
    - Engineers, Natural Scientists
    - Socioeconomists
    - Politicians
    - And Others

Social/Cultural

- Beliefs & Values
- Truth/Perception
- Mental Models
  - Individual
  - Community
- Modeling Philosophy
- Problem Solving Process



Guiding Principle

- Principle 1: Humans are part of, not apart from, aquatic ecosystems and their watersheds.
- Principle 2: Water Is THE Integrator – Essential for Life

Lessons Learned

- Numerous Interdisciplinary Projects
  - Signature Programs/Projects
    - EWQOS
    - NAPAP
    - EMAP
    - South Florida Ecosystem Assessment
    - Water and Watersheds
    - Mid-Atlantic Integrated Assessment
    - EaGLe Atlantic Slope Program
    - WERF Sustainable Water Resources Management

Lessons Learned (Con't)

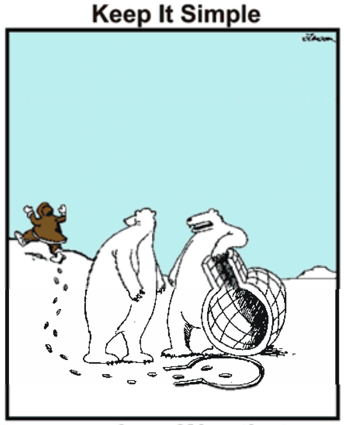
- Start With The End In Mind
  - Achieve Desired Outcomes
  - Make Decisions
    - NAPAP – Acid Rain Problem vs Acid Rain Issue
    - Factors
      - Engineering and Scientific Findings
      - Socioeconomics
      - Politics

Lessons Learned (Con't)

Process

- Use a Suite of Methods (Tools)
- Start with the Simple Methods (Tools)
- Keep It As Simple As Possible, But No Simpler (Einstein)
- It's Data Driven (Smith et al., 2003)

Keep It Simple



"I lift, you grab. ... Was that concept just a little too complex, Carl?

Lessons Learned (Con’t)

- Modeling Principles
  - All Models Are Wrong; But Many Models Are Useful (Box)

  Corollary:
  - All Models are Imperfect; But Many Imperfect Models Add Weight of Evidence
  - All Model Predictions are Relative: But Relative Changes Are Useful.

Implications

- Decision Support Systems
  - Consider the Lessons Learned
  - Consider An Integrated Process
  - No Magic Bullet; No Perfect Tool
  - Weight of Evidence Approach
  - Contribute To Decision-Making
  - Solve Problems and Resolve Issues

Integrated Process

- Bounding the Problem
- Selecting the Tools
- Solving the Problem
- Resolving the Issue

Questions?

Discussion

Integrated Process

Bounding the Problem

Messages

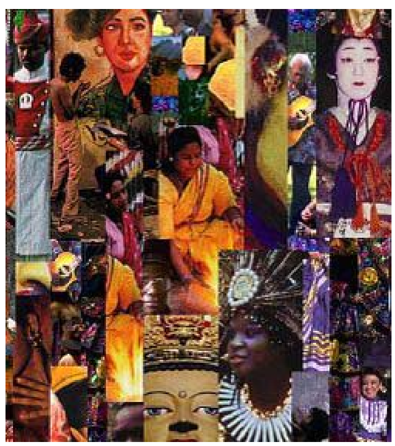
- Begin With The End in Mind
- Make Sure You Know THE Questions
- Make It Relevant To Management

Desired Outcomes

- Ecosystem Services Restored
- Floodplain Restoration
- Ecosystem Sustainability
- Endangered Species Habitat
- Invasive Species Eradication/Mgt
- “Natural Down-stream Flow Regime
- Native Prairie Restoration

Social/Cultural

- Management Is Fundamentally A Social Activity
- Economics Part of Solution
- Consider Socio-Economic Endpt Relationships to Management – Ecol. Indicators



Endpoints

Management Endpts	Ecol. Indicators
Navigation	Fish/Benthos
Eco. Sustain.	Food webs
Drinking Water	ac-ft, Chl a
Flood Control	Channel Depth
Aquatic Life Use	IBI
Wetland Creation	Acreage, WBI
Estuarine Cond.	Sea grass Extent

Relevant Eco. Assess. Endpts

Organism Population	Mussels, Snails, Mammals, T&E Birds, Fishes, Rec. Waterfowl, Reptiles, Amphibians, Insects
Special Places	UMR Driftless Area
Community or Ecosystem	Backwater, Oxbows, Wetlands, Fish Communities

Eco. Assess. Endpts for Great Rivers EMAP 2005

Questions

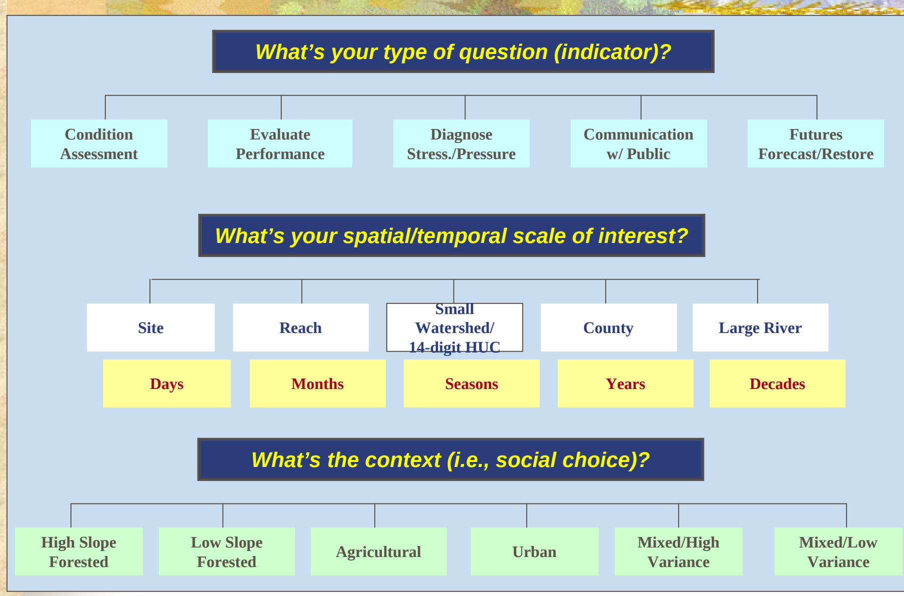
- Ask The Right Questions:
  - Solving the wrong problem
  - Stating in-answerable questions
  - Solving a solution
  - Questions too generic
  - Agreement on answer before questions (Bardwell 1991)

Bounding the Problem

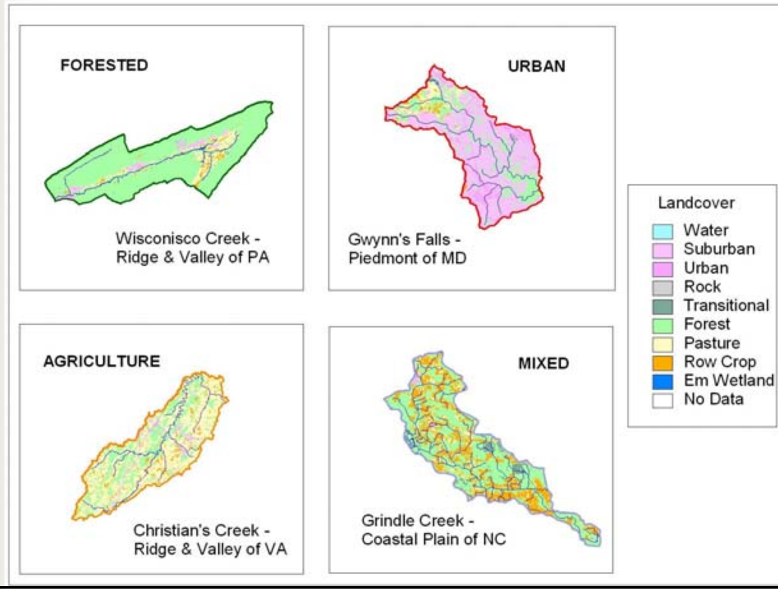
- Ecological Indicators
- Time and Space
- Conceptual Models
- Order of Magnitude Estimates
- Empirical Models

ASC Management Implications

- Managers Want Suites of Tools & Indicators
- Use Depends on:
  - Question Being Asked
  - Time and Space Scale for Answer
  - Context or Social Choice
- Taxonomy of Indicators



Social Choice = Land Use Patterns

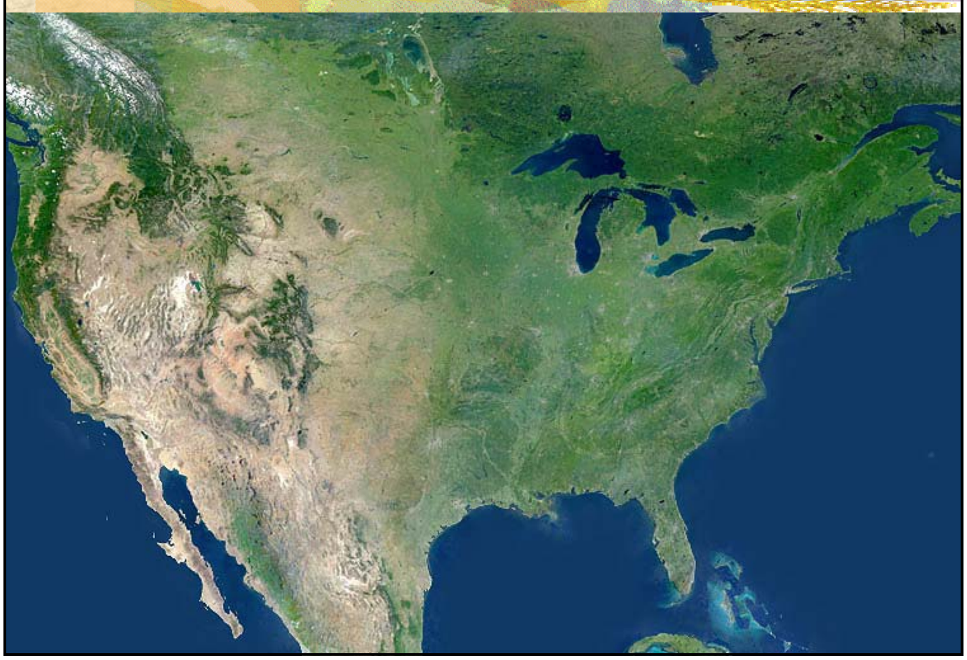


Indicator Taxonomy

Indicator	Ques.	Time	Space	Context
IMBCI	Cond., Diag. Comm.	Yr-Decade	Marsh-Est. Segm	Emergent Marsh
B-IBI	Cond., Diag. Comm.	Decade-Year	Site-Sm. WS	L-S Forest Agriculture
S-WRI	Cond., Diag. Comm.	Season-Year	Reach-Sm. WS	Ag., Urban, Mixed
SBS	Cond., Diagn.	Season-Year	Reach	Ag., Urban, Mixed
Inverse Dist. Wt. Develop	Cond., Diag	Season-Decade	Reach-WS	Urban, Mixed

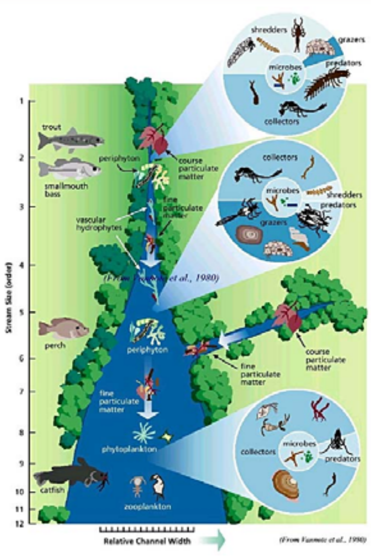
Global Scale

- Hydrologic Cycle Closed Globally
- Holistic
- Continuous Regimes
  - Aquatic
  - Atmospheric
  - Terrestrial
- What Are Time and Space Scales?



River Continuum

- River Continuum Concept
- Seamless Gradients
- Different Processes Dominate



Hierarchy Theory

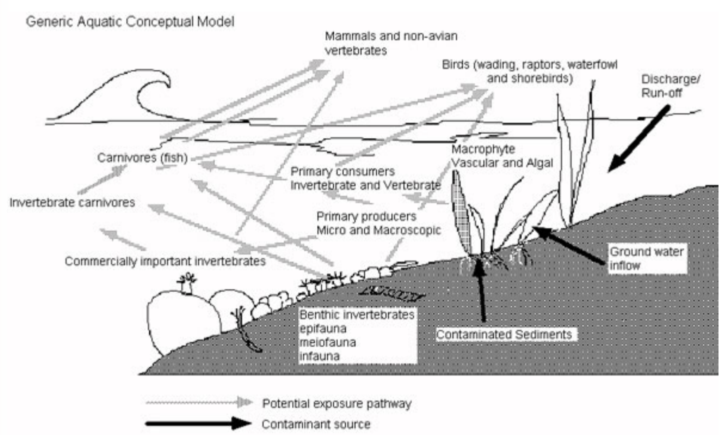
- Level +2 ~ Constant
- Level +1 ~ Slowly Varying
- Level +0 ~ Management Endpoint
- Level -1 ~ Controlling Processes
- Level -2 ~ Noise

Conceptual Models

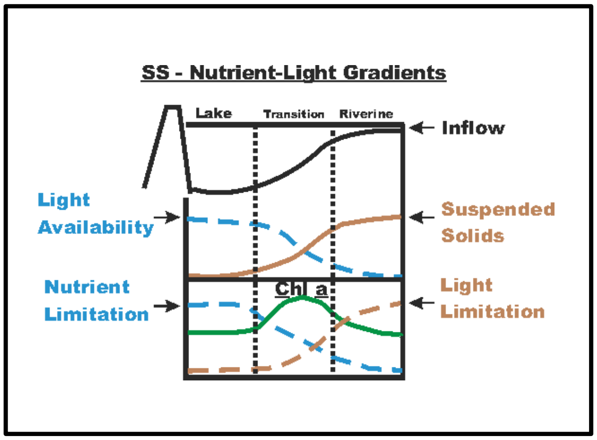
- Henderson and O'Neil (2004)
- Six Step Approach
  - ID Model Objectives, Uses
  - T&S Scales or Model Boundaries
  - ID Structural Components
  - ID Sources of Change
  - Review the Model
  - Implement the Model

Flood Plain Restoration

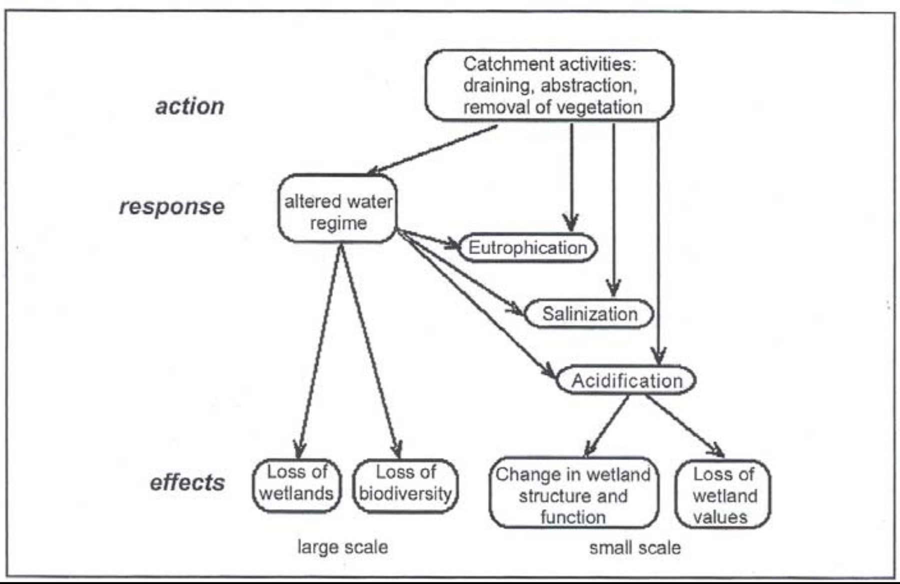
Lake Restoration - Sediment



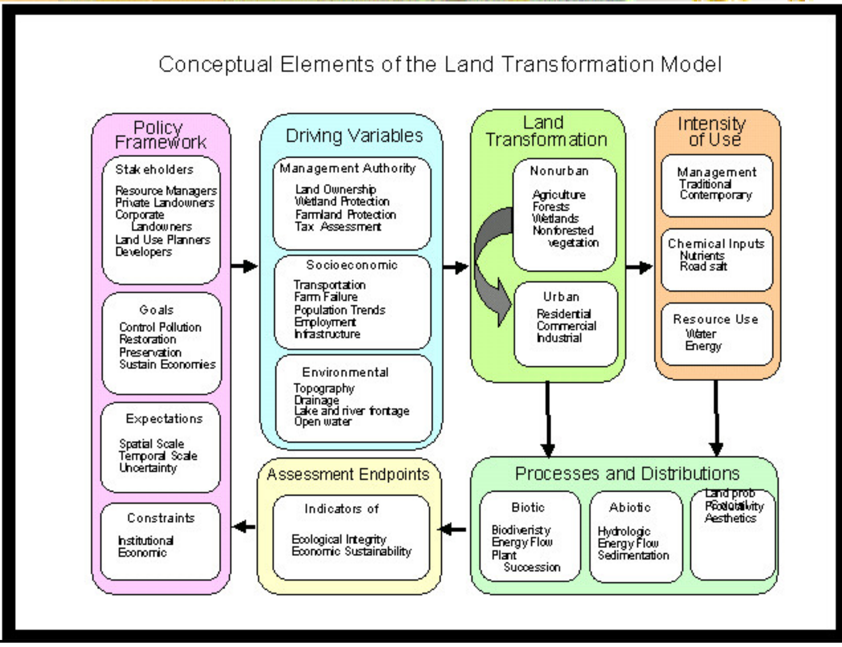
Reservoir Gradients/Transition



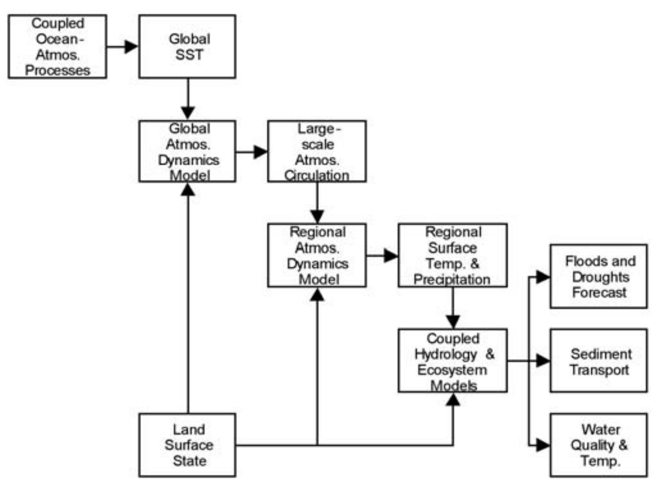
Wetland Effects



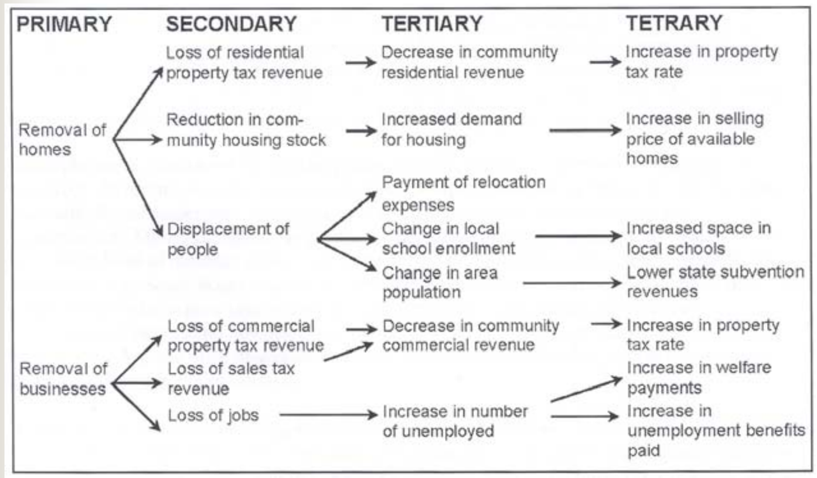
Policy-Science Interactions



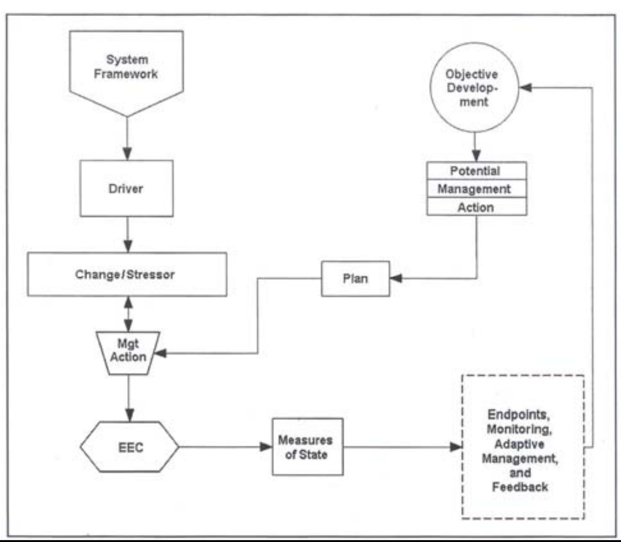
Global Change and Ecohydrology



Transportation Impact Model

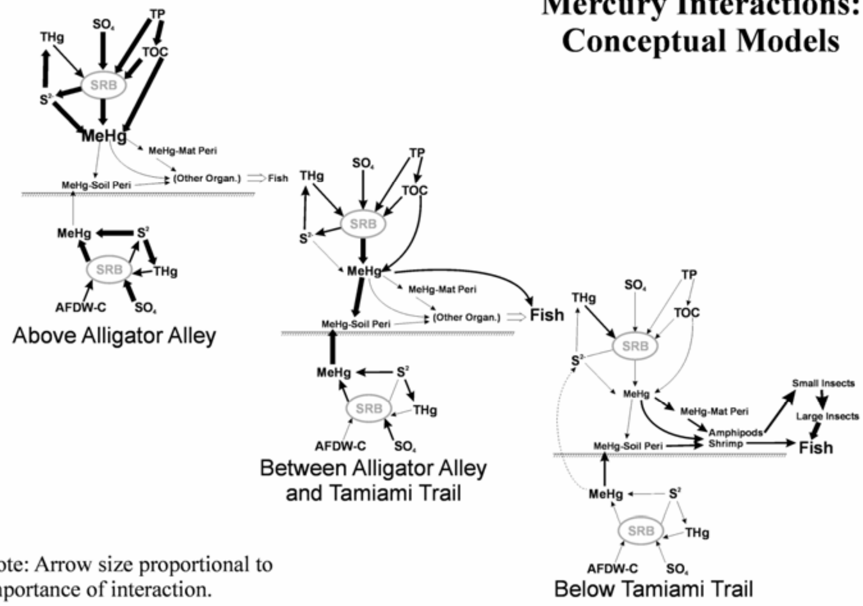


UMR Schematic Model



So. FL Everglades Model

Mercury Interactions: Conceptual Models



Note: Arrow size proportional to importance of interaction.

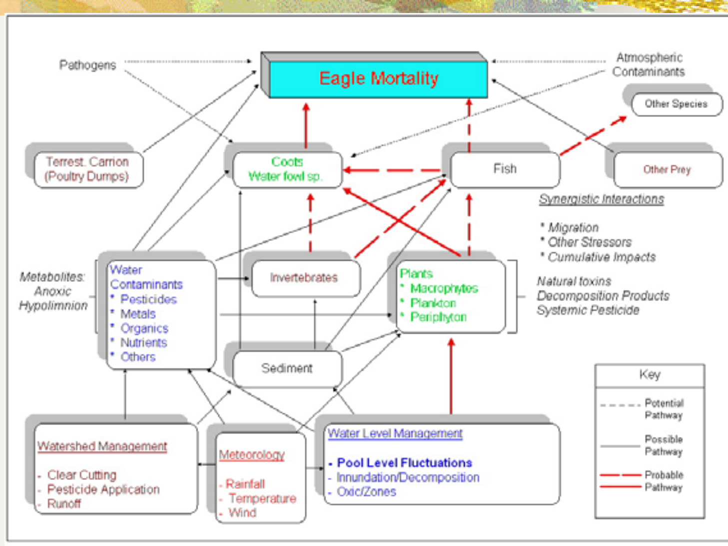


Figure 1. Conceptual Model of Eagle Mortality

Order of Magnitude Estimates

- Rivers
  - Reynolds No. Re = 👎🖫L/💻
    Re ~ 2000 > turbulent, < 2000 laminar flow
- Reservoirs
  - Froude No. Fr = QL/V[(◑👎/👎)gz_m]$^{1/2}$
    Fr ~ 1/✍ << strongly stratified
- Estuaries
  - Richardson No. Ri = (◑👎/👎)$gQ/WU_t^{1/3}$
  - Well mixed 0.08 < Ri < 0.8 strongly stratified

OME (Con’t)

- Corps Reservoir Data Base
  - Drainage Area/Surface Area DA/SA
    - DA/SA < 10 – Shore/Near-shore Imp.
    - DA/SA > 50 – Far upstream unimp.
  - Aspect Ratio L/W
    - L/W < 4 – Both longitudinal & lateral imp.
    - L/W > 4 – Longitudinal dominate

Empirical Relationships

- Rivers
  - DA and Q
    - $Q = 2x10^6 DA^{0.73}$ (Average Annual Q)
    - $Q_t = 0.73\ DA + 6.3$ ($R^2 = 0.6$) (Total Ann. Q)
  - Nutrients
    - $log chl = -1.92 + 1.96 logTP - 0.30(logTP)^2 + 0.12 logDA$ ($R^2 = 0.74$)

Empirical Relationships (Con't)

- Reservoirs
  - Plunge Point
    - $hp = (1/F_d^{\,2})^{1/3}\ (Q_i^{\,2}/W_c^{\,2} g$☽♎/♎$)^{1/3}$
  - Nutrients
    - $[TP_x] = [Tp_i]exp(-$☞☺$_x)$ Plug flow Model
    - $log\ chl\ a = -1.58 + 2.84\ log\ TP - 0.67\ (log\ TP)^2$
  - Fish ($MEI = TDS/z_m$)
    - $log10H = 0.925 + 0.56 log10\ MEI - 0.15 logMEI^2$
      H = Reservoir Sport Fish Harvest, kg/ha

Empirical Relationships (Con't)

- Estuaries
  - Resident Time
    - $FRT = (S_s - S_e / S_s)V/Q_f$
    - $PRT = (31 + 5.8 (10^8)/[86400(5.4 + 14.7\ Q_f)]$
  - Nutrients
    - $Log_{10}chl = -3.7 + 4.3log_{10}TN - 0.9(log_{10}TN)^2$ $(R^2 = 0.84)$
    - $Log_{10}chl = 0.1 + 1.0log_{10}TP$ (N:P >20) $(R^2 = 0.74)$

Time and Space Considerations

- Taxonomy of Indicators
- Time – Space Scales of Empirical Relationships
  - Average Seasonal Chlorophyll - Estuary
  - Fish Harvest ~ 5-10 years - Reservoir
  - Annual Discharge - Watershed

Messages

- Begin With The End in Mind
- Make Sure You Know THE Questions
- Make It Relevant To Management

Questions?

Discussion

Integrated Process

Selecting the Tools

Messages

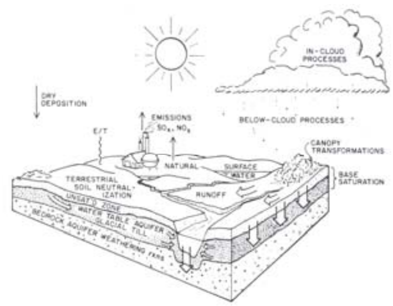
- Use a Suite of Tools
- Consider Time-Space Scales of Interest in Selecting Tools
- Keep It As Simple As Possible, But No Simpler

An Acid Rain Story

- Story of Three Models
  - 100-200 Year Projections for Different Sulfate Emission Scenarios
  - Watershed – Lake – Stream Models
  - Three Different Philosophies
    - Research Tool (ILWAS)
    - Engineering Tool (MAGIC)
    - Steady-State => Dynamic Tool (ETD)

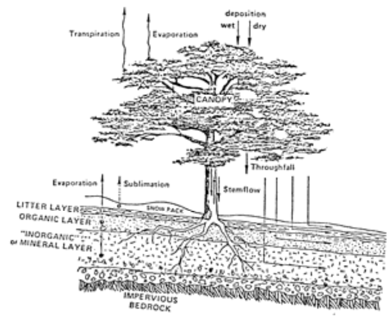
Modeling Philosophies

- ILWAS
  - Understand Acidification Processes
- MAGIC
  - Assess Long-Term Effects of Acidification
- ETD
  - Screen and Understand Lake Acidification



Modeling Philosophies (Con’t)

- ILWAS
  - Daily Dynamics
- MAGIC
  - Annual Changes
- ETD
  - Steady-State and Dynamic Hydrology



Major Processes

Meteorological Data	MAGIC	ETD	ILWAS
Interval	Mo/Yr	Day	Day
Precip	m	mm	cm
Rel. Humid	–	%	%
Min/Max Air Temp	☜C		☜C
Ave Air Temp		☜C	
Cloud Cover	–	Frac.	Frac.
Wind		km/d	m/s

Major Processes (cont.)

Atmospheric Process	MAGIC	ETD	ILWAS
Wet Deposition	X	X	X
Dry Deposition	X	X	X
Hydrologic Processes			
Snow Sublimation	–	X	X
ET	X	X	X
Interception	–	–	X
Snowmelt	X	X	X

Major Processes (cont.)

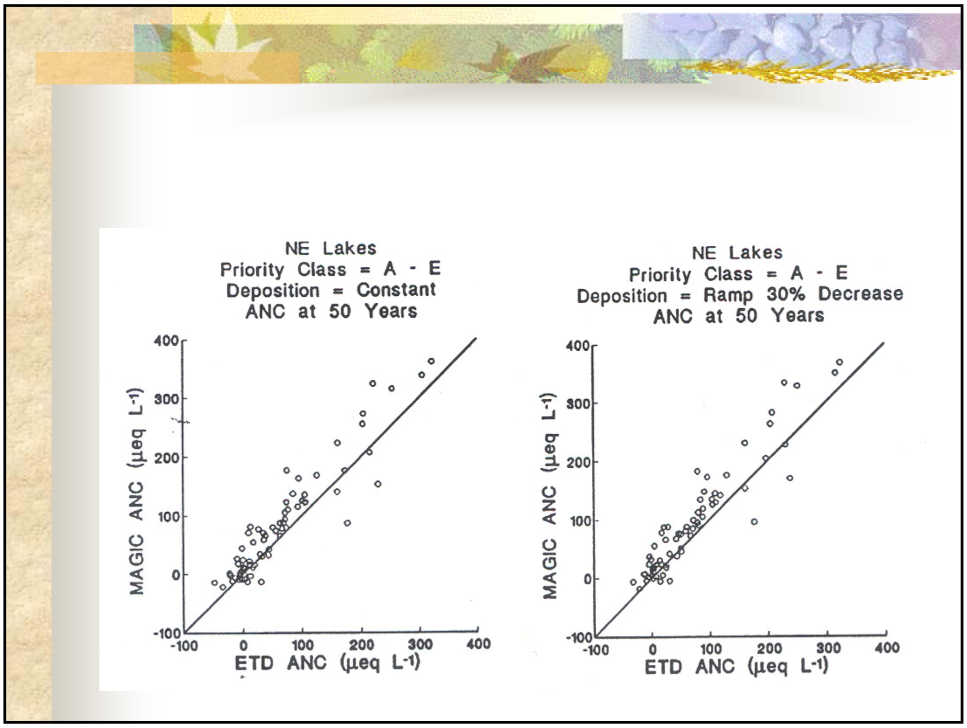
Hydrologic Process. (Con't)	MAGIC	ETD	ILWAS
Overland Flow	X	X	X
Soil Freezing.	–	X	X
Macropore Flow	X	–	–
Unsaturated Subsurface Q	X	X	X
Saturated Subsurface Q	X	X	X
Stream Flow	X	–	X
Lake Stratification	–	–	X
Lake Ice Formation	–	–	X

Major Processes (cont.)

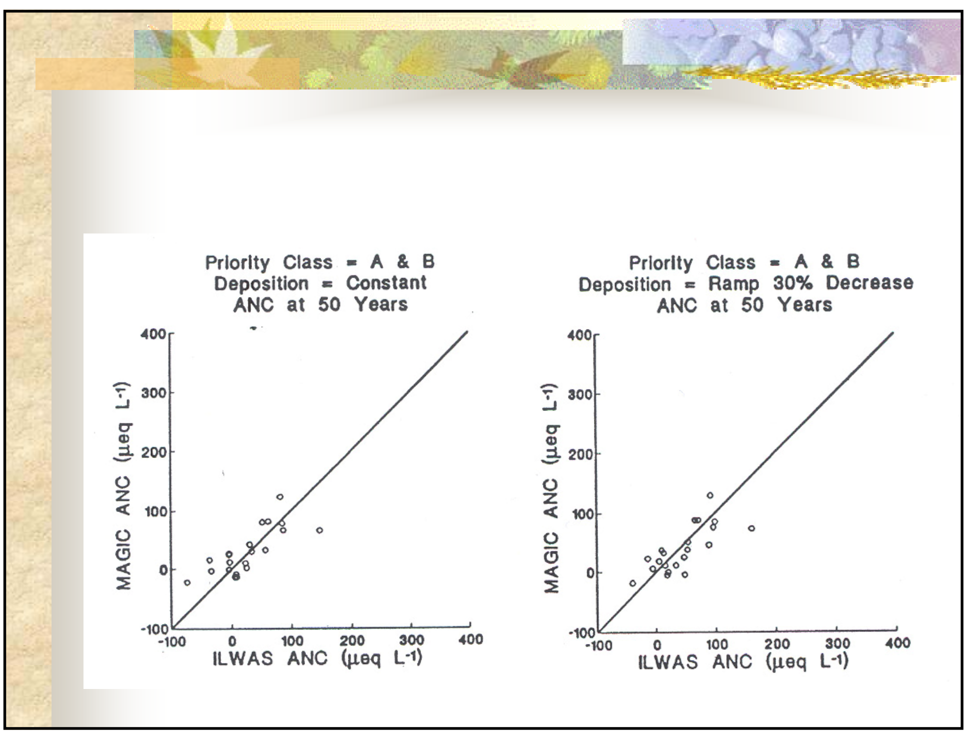
Geochem. Processes	MAGIC	ETD	ILWAS
H_2CO_3 Chemistry	X	X	X
Al Chemistry	X	–	X
Org. Acid Chemistry	X	–	X
Weathering	X	X	X
Anion Retention	X	X	X
Cation Exchange	X	X	X

Major Processes (cont.)

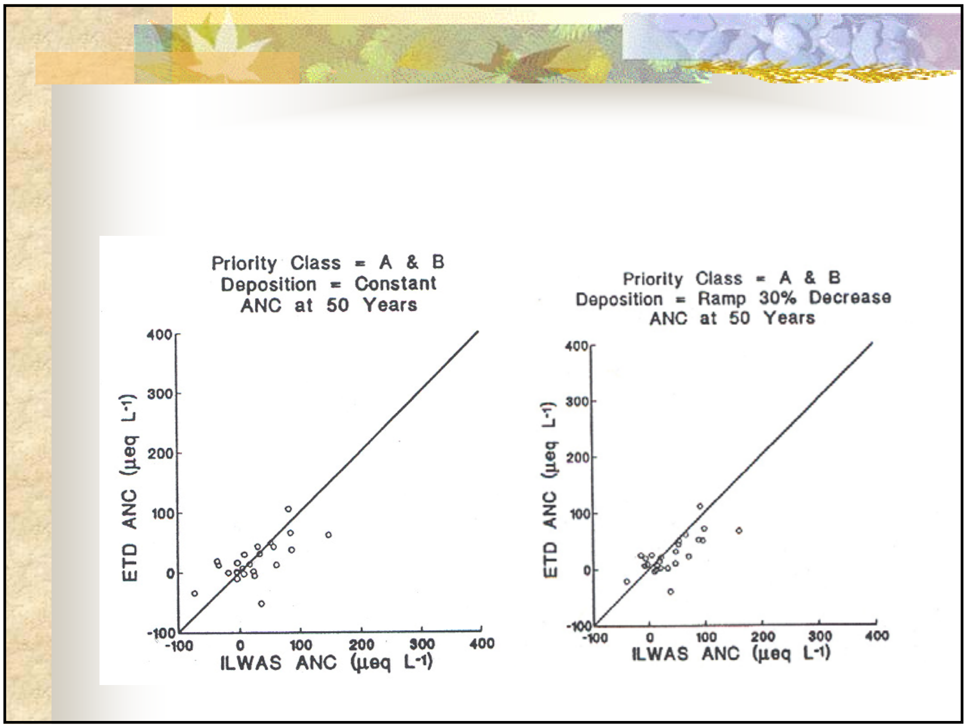
Biogeochem. Processes	MAGIC	ETD	ILWAS
Lake SO_4 Reduction	~	S	S
Soil Nitrification	~	–	X
Nutrient Uptake	~	–	X
Canopy Interception	–	–	X
Litter Decay	–	–	X
Root Respiration	–	–	X

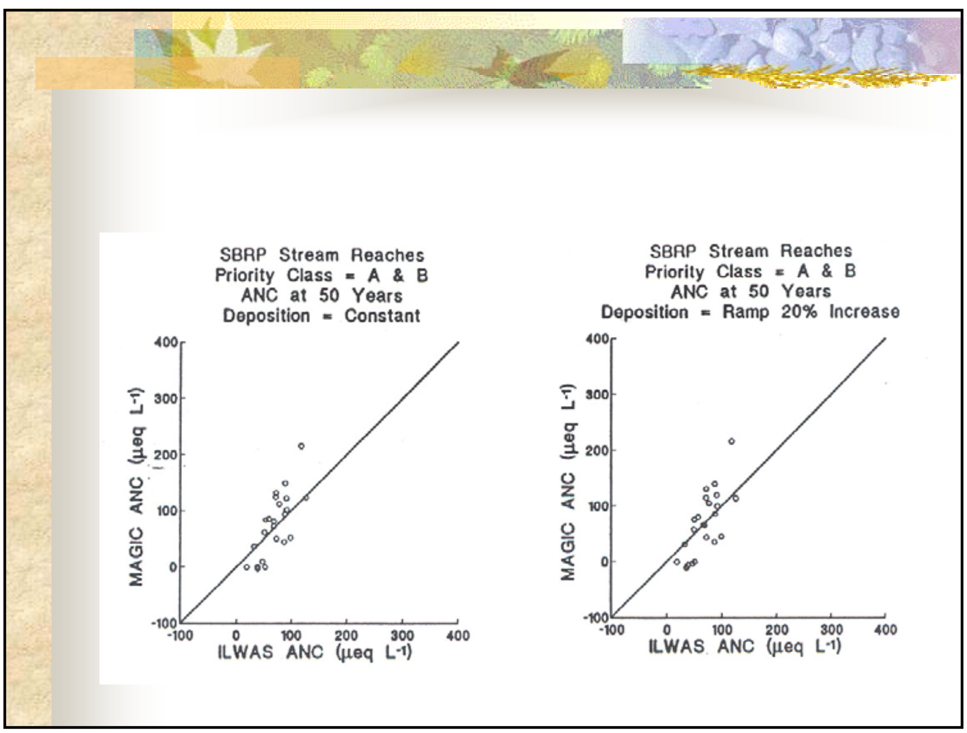


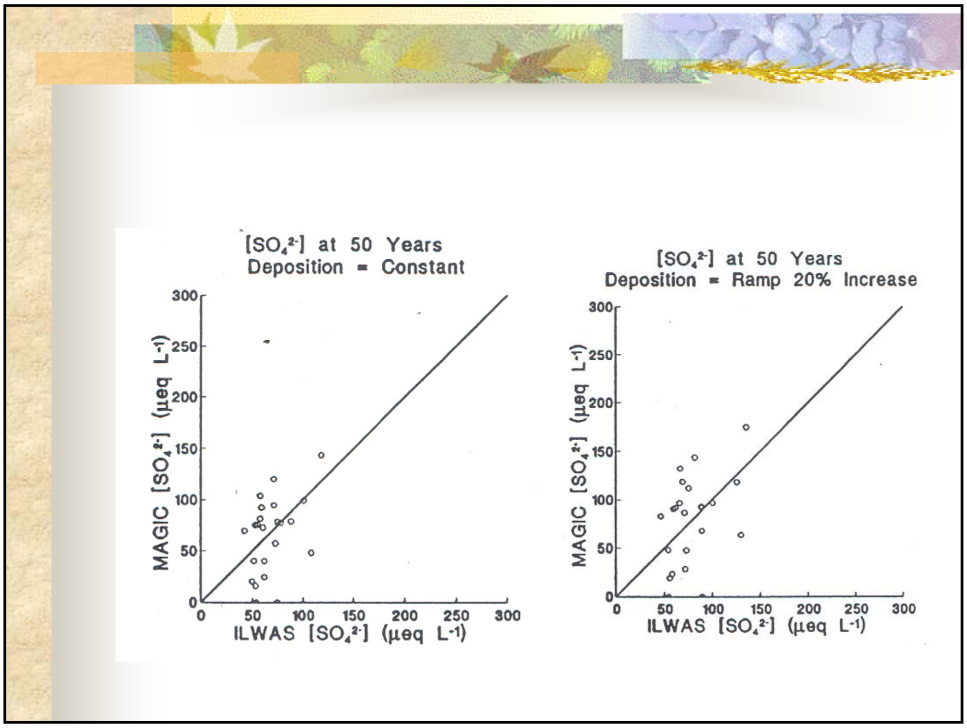
NE Lakes
Priority Class = A - E
Deposition = Constant
ANC at 50 Years
MAGIC ANC (µeq L-1)
ETD ANC (µeq L-1)
NE Lakes
Priority Class = A - E
Deposition = Ramp 30% Decrease
ANC at 50 Years
MAGIC ANC (µeq L-1)
ETD ANC (µeq L-1)



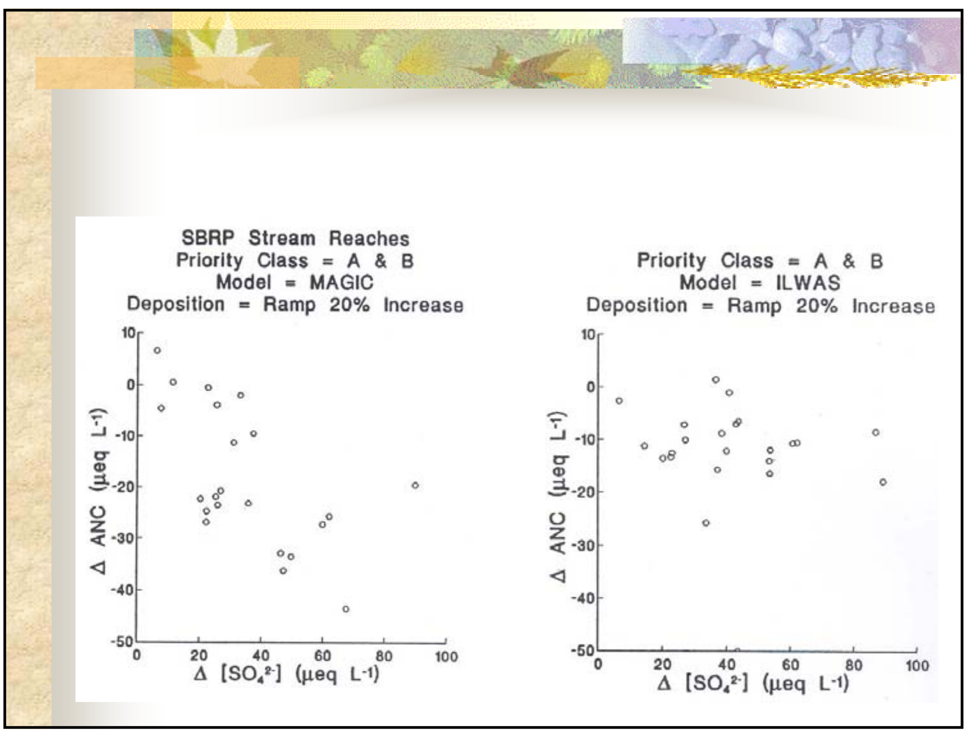
Priority Class = A & B
Deposition = Constant
ANC at 50 Years
MAGIC ANC (µeq L-1)
ILWAS ANC (µeq L-1)
Priority Class = A & B
Deposition = Ramp 30% Decrease
ANC at 50 Years
MAGIC ANC (µeq L-1)
ILWAS ANC (µeq L-1)


Priority Class = A & B
Deposition = Constant
ANC at 50 Years
ETD ANC (µeq L-1)
ILWAS ANC (µeq L-1)
Priority Class = A & B
Deposition = Ramp 30% Decrease
ANC at 50 Years
ETD ANC (µeq L-1)
ILWAS ANC (µeq L-1)


SBRP Stream Reaches
Priority Class = A & B
ANC at 50 Years
Deposition = Constant
MAGIC ANC (µeq L-1)
ILWAS ANC (µeq L-1)
SBRP Stream Reaches
Priority Class = A & B
ANC at 50 Years
Deposition = Ramp 20% Increase
MAGIC ANC (µeq L-1)
ILWAS ANC (µeq L-1)



[SO$_4^{2-}$] at 50 Years
Deposition = Constant
MAGIC [SO$_4^{2-}$] (μeq L^{-1})
ILWAS [SO$_4^{2-}$] (μeq L^{-1})
[SO$_4^{2-}$] at 50 Years
Deposition = Ramp 20% Increase
MAGIC [SO$_4^{2-}$] (μeq L^{-1})
ILWAS [SO$_4^{2-}$] (μeq L^{-1})



SBRP Stream Reaches
Priority Class = A & B
Model = MAGIC
Deposition = Ramp 20% Increase
Δ ANC (μeq L^{-1})
Δ [SO$_4^{2-}$] (μeq L^{-1})
Priority Class = A & B
Model = ILWAS
Deposition = Ramp 20% Increase
Δ ANC (μeq L^{-1})
Δ [SO$_4^{2-}$] (μeq L^{-1})

Holling’s 3 Rules of Thumb

- Need Three Qualitatively Different Speeds of Processes
- 3 to 5 Sets of Variables Adequately Describe System Dynamics
- Have Non-linear Causation and Multistable Behavior

Hierarchy Theory

Level +2 ~ Constant

Level +1 ~ Slowly Varying

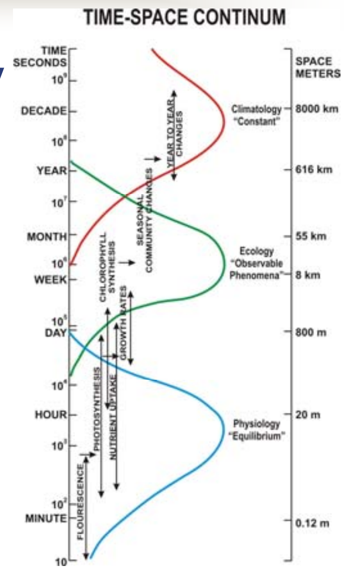
Level +0 ~ Management Endpoint

Level -1 ~ Controlling Processes

Level -2 ~ Noise

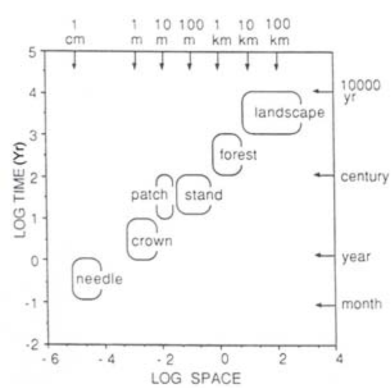
Plankton Hierarchy

- Levels +1, 0, -1 in Green Curve
- Level –2 as Center of Mass in Blue Curve
- Level +2 As Center of Mass in Red Curve

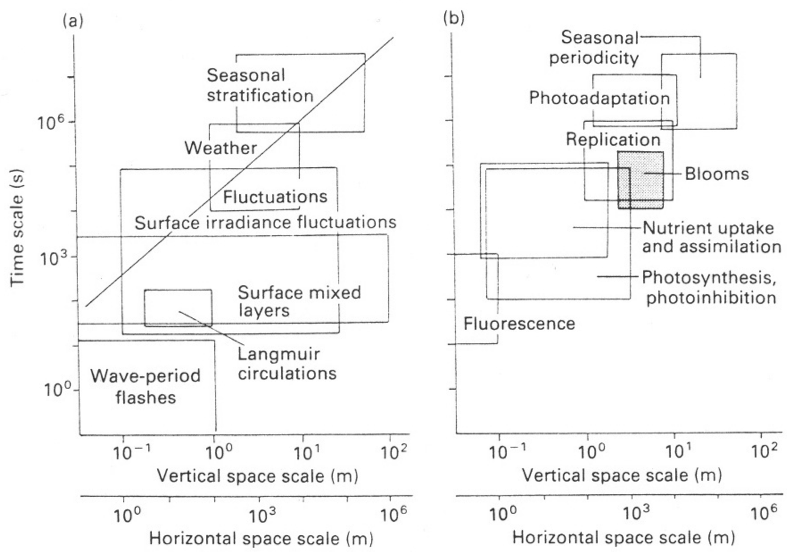


Time – Space Inter-Relationships

- Rule of 10's
- 3 Qualitatively Different Speeds (T-S Scales)
- System Independent
  - Aquatic Systems
  - Terrestrial Systems
  - Atmospheric Systems
  - (Social and Economic Systems)



3-D Scales



Basin Variables & Time (NRC 2000)

Variable	> 1000 yr	Decade to Century	Year to Decade
Geology	Constant	Constant	Constant
Climate	Constant (GCC)	Constant (GCC)	Constant
Vegetation	Variable	Slowly Varying	Constant
Local Relief	Variable	Constant	Constant

Basin Variables & Time (NRC 2000)

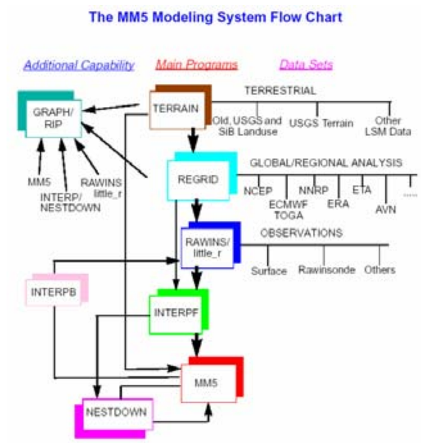
Variable	> 1000 yr	Decade to Century	Year to Decade
Hydrology (Q, Sed/DA)	Variable	Constant	Constant
DA Network Morphology	Variable	Variable	Constant
Hillslope Morphology	Variable	Variable	Constant
Hydrology (Q, Sed.)	Variable	Variable	Variable

Commonalities

- Acidification; Hg Contamination; Global Change; UMR Restoration; Other Large Scale Issues
  - Long Time Scales – Large Space Scales
  - Alternative Tools – Alternative Approaches
  - Not Either – Or; Both – And

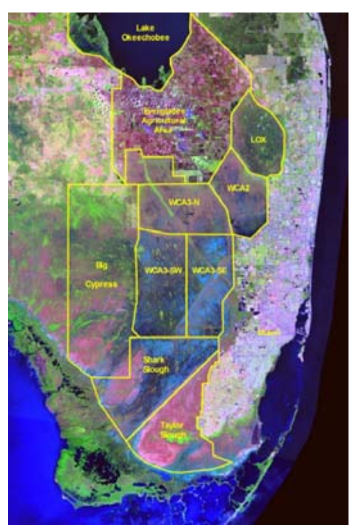
Other Tools

- Downscaling – Upscaling GCM => Regional Modeling
- Reduced Form Equations
  - TAF
  - Reduced Form Equations



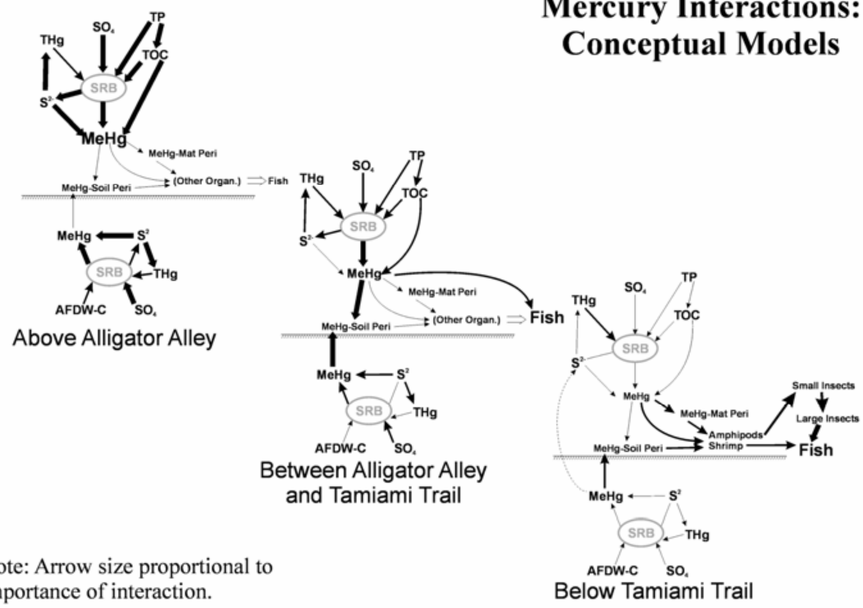
Other Tools

- South Florida Everglades Ecosystem
  - SEM or Path Analysis
  - Mercury Cycling Model
  - Different T-S Scales



So. FL Everglades Model

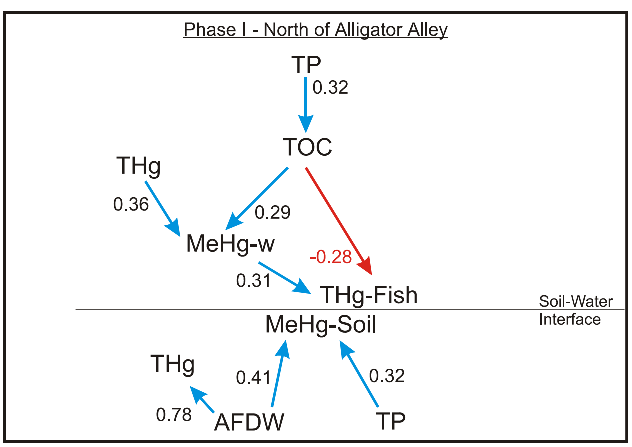
Mercury Interactions: Conceptual Models



Note: Arrow size proportional to importance of interaction.

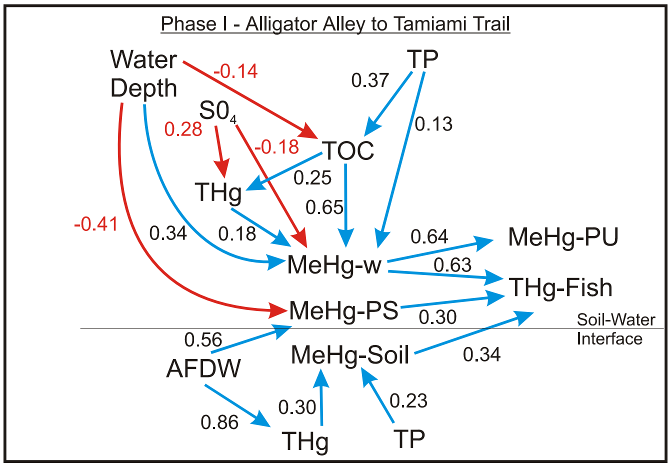
North of Alligator Alley - Phase I

High Concentrations



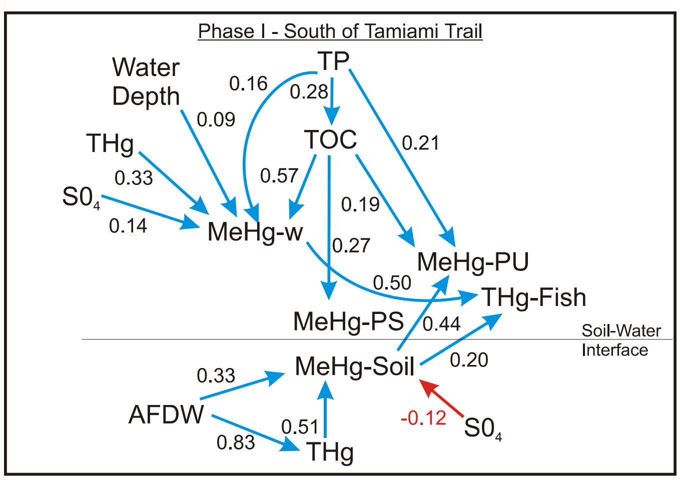
Alligator Alley - Tamiami Trail

Dynamic Area - Phase I



South of Tamiami Trail - Phase I

Low Concentrations



Reduced Equations

- WCA3-SE THg - Fish
  - $\log(\text{THg-F}) = 4.67 - 1.81 \log(\text{TOC}) + 0.47 \log(\text{MeHg}) + 0.43 \log(\text{MeHg-PU})$

    $R^2 = 0.64$, $n=28$
- WCA3-SW THg-Fish
  - $\log(\text{THg-F}) = -0.52 \log(S) + 0.33 \log(\text{MeHg})$

    $R^2 = 0.62$, $n = 22$

Messages

- Use a Suite of Tools
- Consider Time-Space Scales of Interest in Selecting Tools
- Keep It As Simple As Possible, But No Simpler

Questions?

Discussion

Integrated Process

Solving the Problem

Messages

- Use Weight of Evidence Approaches
- Provide Risk or Uncertainty (Certainty) Estimates
- Tailor the Message to the Audience

Weight of Evidence

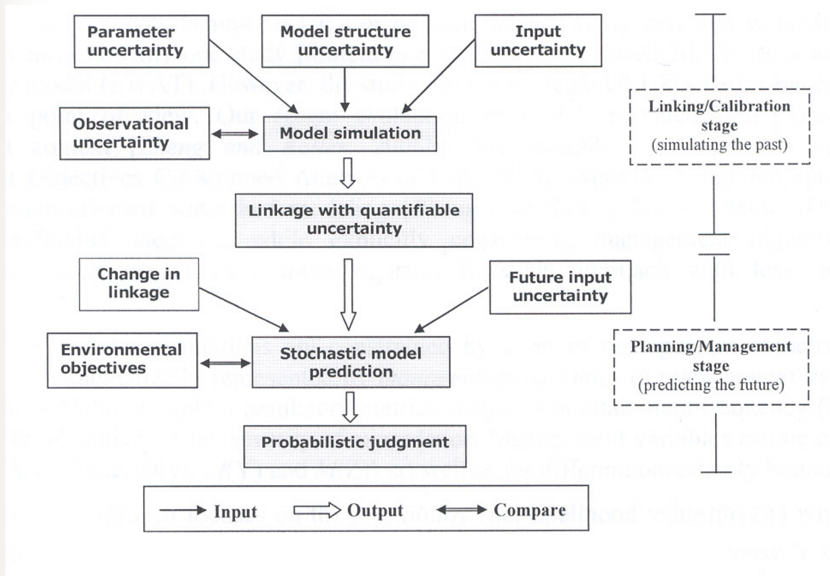
- Coupled Models ⑤ Integrated Models
  - Disparate Time – Space
  - Interface & Boundary Conditions
- Weight of Evidence
  - Multiple Results From Multiple Tools
  - Convergence or Divergence of Results
  - Formal Approaches Needed

Weight of Evidence

- Need Better Weight of Evidence Approaches
  - Relative Risk Models
  - Normalization/Scaling Approaches
  - Intuitive Perspective
  - Expert Elicitation

Certainty of Results

- Uncertainty Typology (Krupnick et al. 2006)
  - Aleatory (randomness, chance)
    - Stocasticity
  - Epistemic (knowledge)
    - Input uncertainty
    - Parameter uncertainty
    - Structural uncertainty
    - Transboundary uncertainty



Additional Uncertainty

- Transboundary Uncertainty
  - Decision Uncertainty
    - Implicit Decisions
    - Ambiguities in Social Objectives
  - Linguistic Uncertainty
    - Miscommunication
    - Missing Networks

Uncertainty Estimates

- Empirical – Chebyschev Inequalities
- OME – Factor of 3-5
- Dynamic Methodology
  - Latin Hypercube
  - RSA
  - GLUE,
  - IBUNE
  - Ensemble
  - Etc.

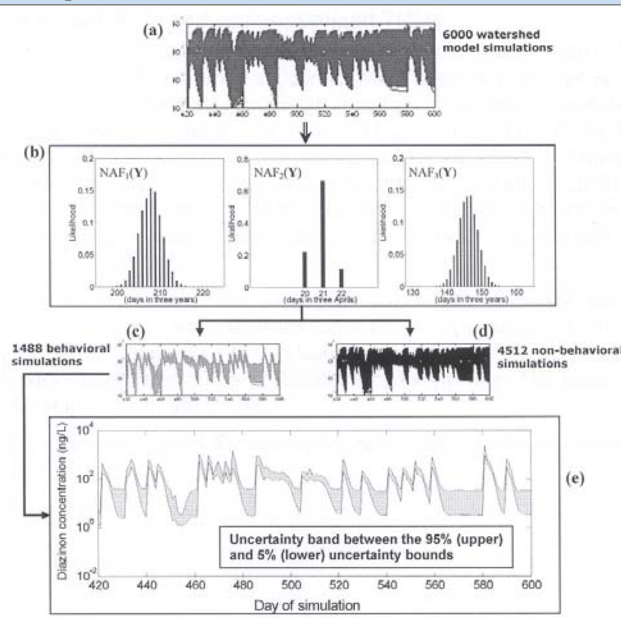
Uncertainty Estimates

- Ensemble Modeling
  - Uses Multiple Models (Tools)
  - Incorporates Several Uncertainty Sources
  - Provides General Likelihood Estimators
  - Potential for DSS

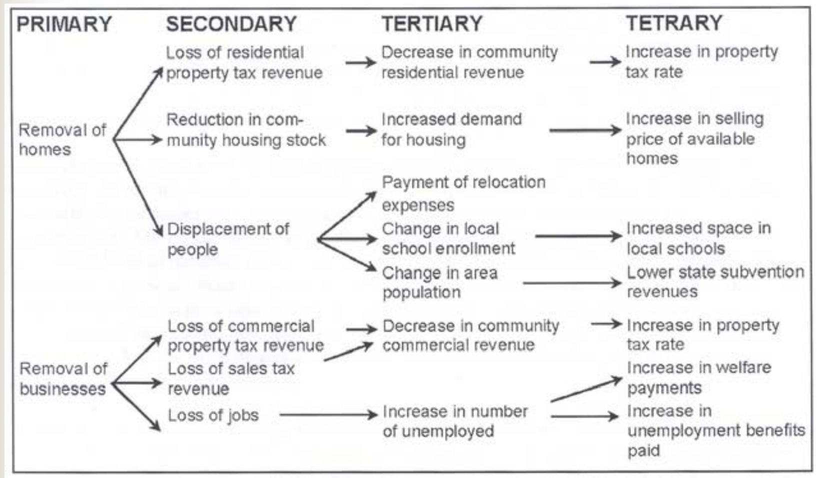
Uncertainty Estimates

- Alternative Approaches
  - SEM or Path Analysis,
  - Analytic Hierarchy Process
  - Fuzzy Logic
  - Multi-attribute Utility Functions
  - Delphi, Elicited Estimates
  - Neural Networks, Genetic Algorithms
  - Cellular Automata

Mgt. Obj. Const. Anal. Uncertainty



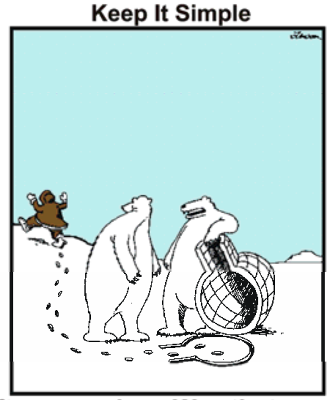
Monte Carlo Markov Chain (MCMC)



Communication

- Marketing Mentality
  - Stay On Message
  - Keep It Simple (KISIS)
  - Single Message
  - Do Not Send Mixed Messages
  - Trusted Source for the Message
  - WIIFM

Keep It Simple



"I lift, you grab. ... Was that concept just a little too complex, Carl?

Communication

- Military Briefing
  - Approach
    - Tell Them What You Are Going To Tell Them
    - Tell Them
    - Tell Them What You Told Them
  - 3 - 6 x Rule
  - Tell Them Again

Messages

- Use Weight of Evidence Approaches
- Provide Risk or Uncertainty (Certainty) Estimates
- Tailor the Message to the Audience

Integrated Process

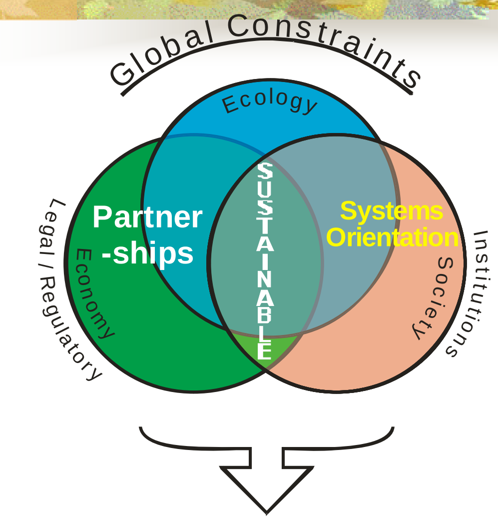
Resolving the Issue

Messages

- Engineering Solutions Necessary, But Not Sufficient
- Socioeconomic Perspective Provides Better Problem Solutions and Issue Resolution
- Objective – Contribute to Decisions

Issue Resolution

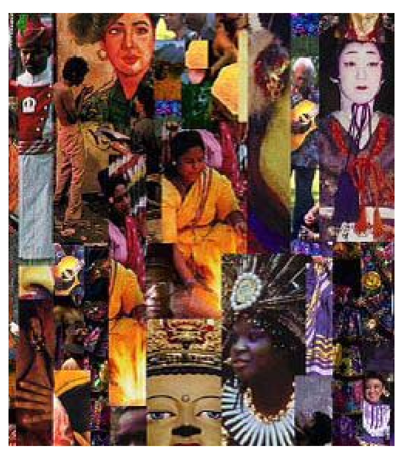
- Integrating Socioeconomic and Environmental/Engineering Approaches
  - Economic
  - Psychometric
  - Sociological Methods



Sustainable Management

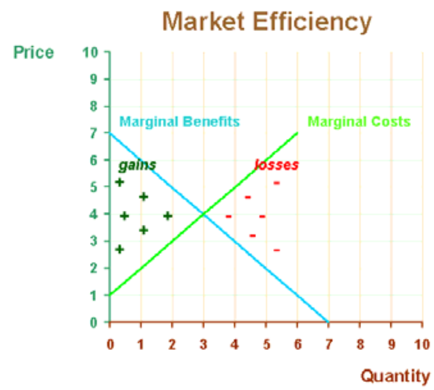
Social/Cultural

- Beliefs & Values
- Social Networking
  - Influencers
  - Networks
- Social Marketing
  - Public Awareness
  - Behavioral Mod.



Economy

- Valuation
  - Market-based
  - Non-market based
  - Ecosystem Services
- Full Cost, Full Value



Ecosystem Services

- Provisioning
  - Food
  - Fresh water
  - Fiber and Wood
  - Fuel, etc.
- Regulation
  - Climate
  - Flood
  - Disease
  - Water Purification
- Cultural
  - Aesthetics
  - Spiritual
  - Recreational
  - Educational
- Supporting
  - Water Cycling Nutrient Cycling
  - Soil Formation
  - Primary Prod

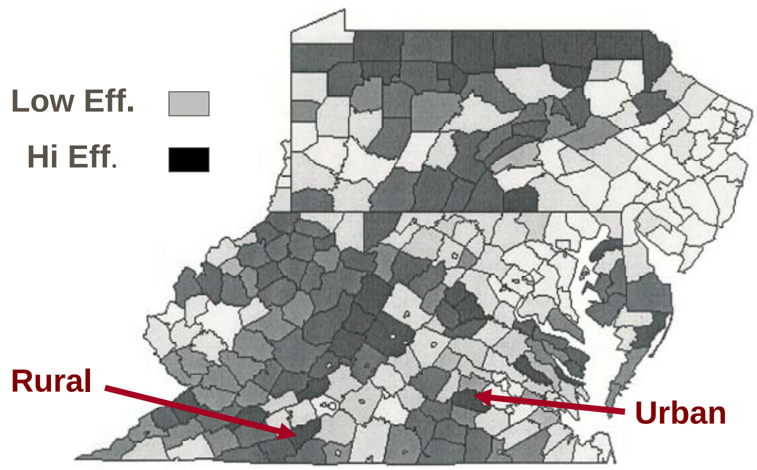
Frontier Analysis

- Production Efficiency
- Comparative Basis
- Compare
  - Environmental indicators
  - Social indicators
  - Economic indicators

Indicators (Input, Output)

- Input
  - EPA's Cancer Risk Index
  - % Developed Land
  - Teacher/Pupil Ratio
  - % HS Grads
  - % Pop < Poverty Income
- Output
  - No. Arts, Rec., Entertainment Establish./mi^2
  - Median House. Income
  - Amenity Index

VEA – Comparative Basis



Unintended Consequences

- What You Don't Know Can Hurt You!
- Need Multiple Perspectives and Inputs
- Integrated Process and Adaptive Mgt.

Whew! Made it out just in time.
Of course, we're equally screwed now!

Messages

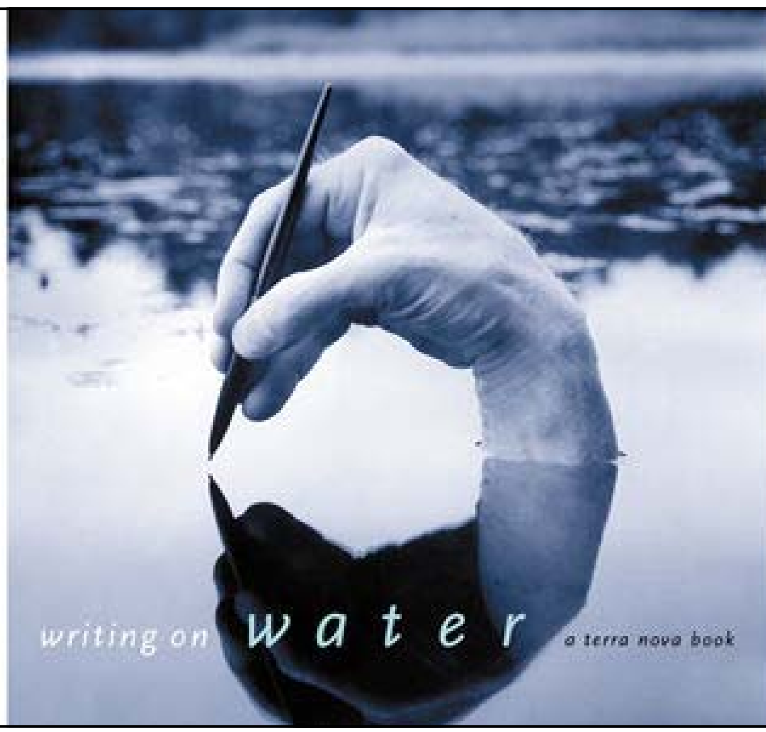
- Engineering Solutions Necessary, But Not Sufficient
- Socioeconomic Perspective Provides Better Problem Solutions and Issue Resolution
- Objective – Contribute to Decisions

Bottom Line

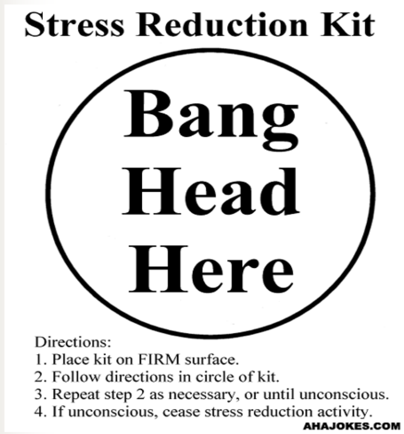
- It’s the Whole;
  Not the Parts
- It’s the Process;
  Not the Product
- It’s the Issue;
  Not the Problem

Questions?

Discussion



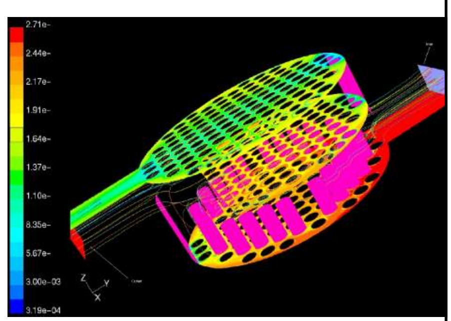
Eliminating Frustration



- Why Do Some Solutions Take and Others Don’t?
- What Makes The Difference?
- Is Banging My Head Against This Wall The Only Way?

Why Won’t Anyone Listen?

- Great Technical Solutions
  - Heterogeneous Photovoltaic/Fuel Cell for WWTP
  - Tidal Hydropower Generation
  - Conservation Tillage, Nutrient Probes




Missouri
Upper Mississippi
Ohio
Arkansas-Red-White
Tennessee
Lower Mississippi
Hypoxic Zone
Gulf of Mexico

Ecological Modeling Workshop at the ERDC, June 06 2007: "Take home "points perceived by John Barko

- **In selecting models for planning applications simple is better, but not overly simple.**
- **It is important to first develop questions and objectives before selecting modeling approaches/specific tools for application. This is an important point to drive home with planners/decision makers.**
- **Model output can and should be used in reexamining and perhaps revising questions/objectives, as part of adaptive management.**
- **Model selection and application of the same can be improved based on knowledge of limiting factors and processes in an ecological context. Thus, modeling and science need to remain coupled.**
- **Use conceptual modeling constructs (box and arrow diagrams) to frame problems, develop testable hypotheses, and develop potential solutions.**
- **Use multiple tools when possible and seek convergence of output in order to establish trends when selecting management/action alternatives.**
- **Models rarely provide answers, but are quite useful in evaluating sensitivity to management actions and policy decisions/changes.**
- **Use models to evaluate range of possible changes (resulting from actions) and rates of change.**
- **Eco-modeling is effective in developing approximations and providing weight when using multiple lines of evidence approach in decision making**
- **Coupled models are not always integrated/ nor do they necessarily need to be integrated.**
- **Empirical models can be perfectly acceptable, depending upon the questions/objectives posed. Complex physics-based "high fidelity" models are great, when they work, and are tied to sound science in the context of ecological processes and function.**
- **Uncertainty is a very important consideration in decision making. Models should explicitly account for uncertainty.**
- **Communication is a very important element in decision making. Modelers, scientists, and decision makers need to be communicative.**

Management Decisions/Questions/Communications

MCDA – Quality quantity issues/transition

DSS framework – facilitates process
with a variety of approaches (suite of tools,
run at different time and space scale but exchange info)
(add conceptual model to general dss framework
Include reference to allow EBA
Heirarchy in approach for time and space scale,
reduce objectives, iterative

Time and space scales/indicators

IT versus Science perspective